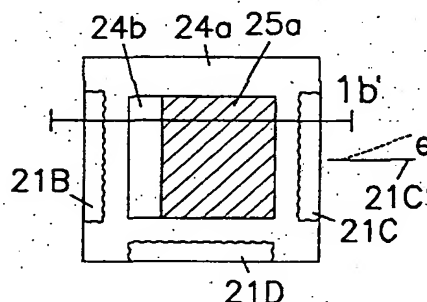




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(54) Title: METHOD OF FABRICATING AND PATTERNING OLEDS



## (57) Abstract

A patterning system (22) with a photoresist overhang (24a) allows material to be deposited onto a substrate (20) in various positions by varying the angle from which the material is deposited, and by rotating the substrate. The patterning system can be used to fabricate a stack of organic light emitting devices on a substrate using the same patterning system and without removing the substrate from vacuum.

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## METHOD OF FABRICATING AND PATTERNING OLEDs

This invention was made with the support of the United States Government under Contract No. F33615-94-1-1444, awarded by the Defense Advanced Research Projects Agency. The United States Government has certain rights in this invention.

### Field of the Invention

The present invention relates to deposition and patterning methods for thin films, and more particularly to photolithographic patterning methods which are suitable for producing organic light emitting devices (OLEDs) suitable for commercial flat panel displays, and to vacuum deposited devices fabricated using such photolithographic patterning methods. More specifically, the present invention provides a method of using a patterning system having an overhang.

### Background of the Invention

Organic light emitting devices, which make use of thin film materials that emit light when excited by electric current, are becoming an increasingly popular technology for applications such as flat panel displays. Popular OLED configurations include double heterostructure, single heterostructure, and single layer, as described in PCT Application WO 96/19792, which is incorporated by reference.

OLED's may be fabricated using shadow mask technology. However, it is difficult to accurately align multiple layers of deposited material using shadow masks, and the masks tend to clog. Moreover, it is difficult to fabricate features smaller than about 300 microns using a shadow mask, whereas OLEDs smaller than about 100 microns by 100 microns, and possibly smaller than about 10 microns by 10 microns, are preferred for a high resolution, full color flat panel display.

An array of 20 micron x 20 micron polymer LEDs has been fabricated using direct photo-ablation with the 193 nm. emission of an excimer laser. S. Noach et al, Appl. Phys. Lett. 69, 3650, 9 Dec. 1996. While this dimension is suitable for a high resolution display, the low speed of laser photo-ablation are undesirable for commercialization.

Photolithographic patterning involves the use of a photoresist to create patterns in a

material deposited on a substrate, and can be used to pattern materials and fabricate devices on a submicron scale, much smaller than can be achieved with shadow mask technology. Photolithographic patterning is also well suited to commercialization because it can be used to quickly fabricate large panels. However, the organic materials used to fabricate OLEDs may be quickly degraded from exposure to deleterious substances such as water, solvents, developers, and even atmospheric conditions. In particular, many of the chemicals used in photolithographic processing, such as solvents and developers used to wash away photoresist, may rapidly degrade such organic materials. Great care should be taken to ensure that the organic materials are not exposed to deleterious substances during the patterning of top electrodes and afterward.

U.S. Patent No. 5,294,870 to Tang discloses the use of a series of parallel walls formed by photolithography prior to deposition of an organic EL layer such that photolithographic patterning steps or wet chemistry are not required after the organic EL medium is deposited.

It is known to use a multi-layer photoresist system with an overhang to deposit materials with sloped edges. W.R. Runyan & K.E. Bean, Semiconductor Integrated Circuit Processing Technology, p.560, Addison-Wesley, 1990. It is also known to use a photoresist system with an overhang to deposit small features, and to facilitate the lift-off of photoresist after material has been deposited in applications such as the fabrication of narrow gate gallium arsenide transistors.

#### Summary of the Invention

A new processing method for patterning small features in organic thin films using photolithographic patterning is described. In this method all photolithographic processing steps are performed prior to organic film deposition. The organic films and electrodes that comprise a SOLED, or similar multi-electrode organic-based device, are then deposited in sequence without being removed from vacuum. This method avoids exposure of the organic layers to conventional photolithographic solvents, such as tri-chloroethylene, acetone, methanol, ethanol, and propanol, that can modify mechanical and electrical properties of organic thin films.

In accordance with an embodiment of the present invention, a method of fabricating an organic thin film device is provided that includes the steps of: creating a patterning system

having an insulation layer and a photoresist layer with a photoresist overhang on a substrate having a plurality of contact pads; depositing through the patterning system a first electrode that electrically connects to a first contact pad of said plurality of contact pads; depositing through the patterning system a organic layer that electrically connects to the first electrode; and depositing through the patterning system a second electrode that electrically connects to the first organic layer and a second contact pad of said plurality of contact pads.

In accordance with an embodiment of the present invention, a method of fabricating a stacked organic thin film device is provided that includes the steps of: creating a patterning system having an insulation layer and a photoresist layer with a photoresist overhang on a substrate having a first contact pad, a second contact pad, a third contact pad, and a fourth contact pad; depositing through the patterning system a first organic layer that covers and electrically connects to the first contact pad; depositing through the patterning system a first electrode that electrically connects to the second contact pad and the first organic layer; depositing through the patterning system a second organic layer that electrically connects to the first electrode; depositing through the patterning system a second electrode that electrically connects to the third contact pad and the second organic layer; and depositing through the patterning system a third organic layer that electrically connects to the second electrode; depositing through the patterning system a third electrode that electrically connects to the fourth contact pad and the third organic layer.

In accordance with an embodiment of the present invention, a method of fabricating a stacked organic thin film device is provided that includes the steps of: creating a patterning system having an insulation layer and a photoresist layer with a photoresist overhang on a substrate having a first contact pad, a second contact pad, a third contact pad, and a fourth contact pad; depositing through the patterning system a first organic layer that covers and electrically connects to the first contact pad; depositing through the patterning system a first electrode that electrically connects to the second contact pad and the first organic layer; depositing through the patterning system a second organic layer that electrically connects to the first electrode; depositing through the patterning system a second electrode that electrically connects to the third contact pad and the second organic layer; depositing through the patterning system an insulating layer on top of the second electrode; depositing through the patterning system a third electrode on top of the insulating layer that electrically connects to the fourth contact pad, and is electrically insulated from the second electrode by the

insulating layer; depositing through the patterning system a third organic layer that electrically connects to the third electrode; and depositing through the patterning system a fourth electrode that electrically connects to the second contact pad and the third organic layer.

5           The present invention provides a technique for fabricating OLED devices using photolithography while reducing the possibility of contamination of the organic layers by deleterious substances such as solvents, developers, water, air or other environments which can degrade such organic layers. In accordance with the present invention, it is possible to use chemicals that are deleterious to the organic materials used in OLEDs both before and  
10           after the organic material is deposited. The present invention therefore allows the fabrication of OLED devices on the small scale made possible by photolithography.

          The present invention uses a patterning system with an overhang and an undercut such that a protective cap can be deposited using the same patterning system used to deposit the organic layer. First, the organic layer is deposited from a direction substantially  
15           perpendicular to the substrate on which the patterning system is formed. Then, the protective cap is deposited from an angle, such that it is deposited into the undercut as well as onto the organic layer. As a result, the protective cap completely covers the organic layer, i.e., the protective cap is deposited on top of and around the organic layer such that the organic layer is no longer exposed from any direction. Preferably, the protective cap is deposited over the  
20           organic layer without removing the organic layer from vacuum. Once the protective cap is deposited, the organic layer is protected from exposure to deleterious substances such as developers and solvents used in subsequent processing, air, and moisture. The protective cap may also increase the shelf-life as well as the operational life of OLED devices.

          While the processes presented below relate to the fabrication of an OLED device, the  
25           present invention can be used to fabricate other vacuum deposited electronic devices that make use of materials which are sensitive to exposure to deleterious substances.

          The present invention provides a method of fabricating an electronic device, e.g., an organic light emitting device, including the steps of forming on a substrate a patterning system having an undercut; depositing a material, e.g., an organic light emitting material,  
30           through the patterning system; and depositing a protective cap, which completely covers the material, through the patterning system.

          The present invention further provides a method of fabricating an organic light

emitting device, including the steps of depositing and patterning a bottom electrode onto a substrate; depositing and patterning an insulating strip over the result of said step of depositing and patterning a bottom electrode; forming a patterning system having an undercut over the result of said step of depositing an insulating strip; depositing an organic light emitting material through the patterning system; and depositing a protective cap, which completely covers the organic light emitting material, through the patterning system.

The present invention further provides an organic light emitting device, that includes a bottom electrode; an organic light emitting material electrically connected to said bottom electrode; and a protective cap electrically connected to and completely covering said organic light emitting material.

The present invention further provides an organic light emitting device, that includes a bottom electrode; a top electrode; an organic light emitting material electrically connected to said bottom electrode and said top electrode; and a protective cap completely covering said top electrode and said organic light emitting material.

The present invention further provides a stack of organic light emitting devices, that includes (a) a first device, having (i) a bottom electrode; (ii) an organic light emitting material electrically connected to said bottom electrode; (iii) a protective cap electrically connected to and completely covering said organic light emitting material; and (b) a second device stacked with said first device.

The present invention further provides a stack of organic light emitting devices, that includes (a) a first device having: (i) a bottom electrode; (ii) a top electrode; (iii) an organic light emitting material electrically connected to said bottom electrode and said top electrode; and (iv) a protective cap completely covering said top electrode and said organic light emitting material; and (b) a second device stacked with said first device.

The present invention further provides a patterning system, that includes an insulating layer deposited on a substrate; and a photoresist layer deposited on said insulating layer having an overhang that extends over an undercut formed in said insulating layer.

The present invention further provides a method of forming a patterning system, comprising: depositing an insulating layer onto a substrate; depositing a photoresist layer onto the insulating layer; patterning the photoresist layer; and wet etching the insulating layer to form an undercut under the photoresist layer.

### Brief Description of the Drawings

Fig. 1a shows a top view of a patterning system as used to deposit a layer from an angle onto a stationary substrate in accordance with an embodiment of the present invention.

Fig. 1b shows a cross-section of the patterning system of Fig. 1a.

5 Fig. 1c shows a top view of the patterning system of Fig. 1a as used to deposit a layer from an angle onto a rotating substrate in accordance with an embodiment of the present invention.

Fig. 1d shows a cross-section of the patterning system of Fig. 1c.

10 Figs. 2a through 2p shows an embodiment of the present invention as it appears after various processing steps.

Fig. 3 shows a cross-section of a double heterostructure embodiment of the present invention.

Fig. 4 shows a cross-section of a single heterostructure embodiment of the present invention.

15 Fig. 5a shows a top view of an embodiment of the present invention having contact pads and transmission pads used to transmit power.

Fig. 5b shows a cross-section of the contact pads and transmission pads of Fig. 5a.

20 Fig. 6 shows a top view of an embodiment of the present invention having an array of pixels with the metal lines and transmission pads used to transmit power to devices fabricated on top of the pixels.

Fig. 7a shows a top view of an embodiment of the present invention having two electrodes connected a single contact pad.

Fig. 7b shows a cross section of the embodiment of Fig. 7a.

Fig. 8 is a cross-section of an embodiment of the present invention.

25 Fig. 9 is a plan view of an array of devices, where a single device of the array is depicted by Fig. 1.

Fig. 10 is a cross-section of a patterning system with an insulating layer used to fabricate the present invention.

Fig. 11 is a cross-section of a stacked embodiment of the present invention.

30 Fig. 12 is a cross-section of a double heterostructure embodiment, showing parts of the embodiment of Fig. 1 in greater detail.

Fig. 13 is a cross-section of a single heterostructure embodiment, showing parts of the



embodiment of Fig. 1 in greater detail.

Fig. 14 is a cross-section of an embodiment of the present invention with a phosphor down conversion layer.

Fig. 15 is a cross section of an embodiment of the present invention with a background of an optically absorbent material.

Fig. 16 is a cross-section of an embodiment of the present invention with a loss limiting layer.

Fig. 17a is an optical micrograph of an embodiment of the present invention.

Fig. 17b shows I-V plots, i.e., current v. voltage, for an embodiment of the present invention.

Fig. 17c shows plots of light intensity v. current for an embodiment of the present invention.

#### Detailed Description

The present invention will be described with reference to the illustrative embodiments in the following processes and drawing figures.

A patterning system 22, comprising an insulating layer 23 and a photoresist layer 24, which has an overhang 24a and an opening 24b, can be used to deposit material onto substrate 20 in different patterns by varying the angle and direction from which the material is deposited, as well as by rotating substrate 20 about an axis 20' substantially normal to substrate 20, as will now be described with reference to Figs. 1a through 1d.

Figs. 1a and 1b show the angular deposition of a layer 25a onto substrate 20, which is stationary having contact pads 21, including contact pads 21A, 21B, 21C and 21D. Fig. 1a is a top view, and Fig. 1b is a cross section taken through line 1b' of Fig. 1a. Layer 25a is deposited from an angle  $\theta$  that is measured as an angle from an axis 20' normal to substrate 20, and a direction  $\phi$  that is measured as an angle from an axis 21C'. Because substrate 20 is held stationary while layer 25a is deposited, the shape and size of layer 25a are defined by the shape and size of opening 24b in photoresist 24. Angle  $\theta$  and direction  $\phi$  determine the position of layer 25a on substrate 20. In Figs. 1a and 1b,  $\theta$  is about  $30^\circ$  and  $\phi$  is about  $180^\circ$ , such that layer 25a is deposited over contact pad 21C, but not contact pads 21B and 21D.

Figs. 1c and 1d show a layer 25b angularly deposited onto substrate 20 as substrate 20 is rotating about axis 20'. Fig. 1c is a top view, and Fig. 1d is a cross section taken through

line 1d' of Fig. 1c. The rotation of substrate 20 causes direction  $\phi$  from which layer 25b is deposited to change relative to substrate 20 throughout deposition, and allows layer 25b to cover a larger area of substrate 20 than would be covered if substrate 20 were held stationary. Layer 25b is deposited from an angle  $\theta$ , which determines the size of layer 25b.

#### Patterning System

A process for fabricating patterning system 22 in accordance with an embodiment of the present invention will now be described with reference to Figs. 1a and 1b.

- 1) Deposit an insulating layer 23. Insulating layer 23 is preferably deposited to a thickness of about 1.5 to 3 microns, and more preferably to a thickness of about 2 microns. Insulating layer 23 can be made of any insulating material that can be wet etched to form an undercut and photoresist overhang 24a. For example, insulating layer 23 can be made of SiO, SiO<sub>2</sub>, or SiN<sub>x</sub> deposited by e-beam or plasma enhanced chemical vapor deposition, or polyimide deposited by spinning.
- 2) Deposit photoresist layer 24 by spinning onto insulating layer 23 to a thickness of about 1 to 2 microns. Photoresist layer 24 can be made of AZ4210 or AZ4110, from Hoechst Celanese Corporation, for example.
- 3) Soft bake photoresist layer 24 at a temperature and time which depend on the layer material and the baking method. For example, if AZ4210 is used, the soft bake may be for 3 minutes at 105 °C.
- 4) Selectively expose opening 24b, but not overhang 24a, to radiation and develop. While the present embodiment describes the use of a positive photoresist, i.e. a photoresist that can be removed by developer only where exposed to radiation, it is also possible to practice the present invention using negative photoresist, i.e. a photoresist that can be removed in developer only where not exposed to radiation, by exposing overhang 24a, but not opening 24b.

- 5) Wet etch insulating layer 23, creating overhang 24a. By controlling the etch temperature, etch time, etchant concentration, etchant stir speed, and the thickness to which insulating layer 23 is deposited, the size of overhang 24a can be controlled. For example, a mixture of 70 ml BOE (buffered oxide etchant) (10:1), which is 36.5% (w/w) ammonium fluoride, 4.5% (w/w) hydrofluoric acid, and 59% (w/w) deionized water, with 5 ml hydrofluoric acid (49% in deionized water) can be used at 20 °C for 4.5 minutes at a stir speed of 400 rpm to etch a 2 micron thick SiO<sub>2</sub> insulating layer 23 deposited by plasma enhanced chemical vapor deposition to create a 10 micron overhang 24a. A smaller overhang 24a of 2 microns can be obtained by using BOE (10:1) at 15 °C for 8 minutes with no stir on a 1.7 micron thick SiO<sub>2</sub> insulating layer 23 deposited by electron beam evaporation. The etchant used to etch insulating layer 23 may not etch structures underlying insulating layer 23, such as substrate 20 and contact pads 21. For example, if BOE (10:1) is used to etch insulating layer 23, substrate 20 should not be a material which would be etched by BOE, e.g. SiO<sub>2</sub> or SiN<sub>x</sub>.

#### Stacked Organic Light Emitting Devices

Figs. 2o and 2p show a three color SOLED fabricated in accordance with an embodiment of the present invention. A contact pad 21A, a first organic layer(s) 31, a first electrode 32, a second organic layer(s) 33, a second electrode 34, a third organic layer(s) 35 and a third electrode 36 are stacked in that order. A protective cap 38 covers any exposed surface of organic layer(s) 31, 33 and 35, and electrodes 32, 34 and 36. First organic layer(s) 31 is disposed between and electrically connected to contact pad 21A and first electrode 32. Second organic layer(s) 33 is disposed between and electrically connected to first electrode 32 and second electrode 34. Third organic layer(s) 35 is disposed between and electrically connected to second electrode 34 and third electrode 36. Light emission from first organic layer(s) 31 occurs when a voltage is applied between contact pad 21A contact pad 21B, which is electrically connected to first electrode 32. Light emission from second organic layer(s) 33 occurs when a voltage is applied between contact pads 21B and 21C, which are electrically connected to first electrode 32 and second electrode 34, respectively. Light emission from third organic layer(s) 35 occurs when a voltage is applied between contact

pads 21C and 21D, which are electrically connected to second electrode 34 and third electrode 36, respectively. The intensity of the light emitted is determined by the magnitude of the current resulting from the applied voltage. Appropriate selection of light emitting organic materials for first organic layer(s) 31, second organic layer(s) 33 and third organic layer(s) 35, allows device 10 to emit any of various combinations of red, green and blue light by controlling the voltages on contact pads 21A, 21B, 21C and 21D.

A process for fabricating the three color SOLED device 10 of Figs. 2o and 2p, in accordance with an embodiment of the present invention, will now be described with reference to Figs. 2a through 2p. While the fabrication of a single pixel is described, an entire array of pixels can be fabricated simultaneously. Figs. 2b, 2d, 2f, 2h, 2j, 2l, 2n and 2p are cross sections taken through lines 2b', 2d', 2f', 2h', 2j', 2l', 2n' and 2p' of Figs. 2a, 2c, 2e, 2g, 2i, 2k, 2m and 2o, respectively. Insulating layer 23 and photoresist layer 24 are not shown in Figs. 2a, 2c, 2e, 2g, 2i, 2k, 2m and 2o so that device 10 can be more clearly illustrated.

Figs. 2a and 2b show substrate 20 with contact pads 21 prior to the fabrication of device 10. Substrate 20 provides a foundation upon which device 10 may be fabricated, and transmits power to device 10. Contact pads 21 provide a convenient geometry for the transmission of power to device 10. In one embodiment, device 10 transmits light through substrate 20 to a viewer, in which case substrate 20 and contact pad 21A should be transparent, i.e. the material, at the thickness used, is capable of transmitting light of the wavelengths emitted by device 10, preferably transmitting substantially all of the light emitted. If device 10 is to transmit light through substrate 20, substrate 20 is preferably transparent glass, quartz, sapphire or plastic, and contact pad 21A is preferably a conductive metal such as gold, silver or aluminum, preferably deposited to a thickness of about 50 - 200 Å and more preferably to a thickness of about 100Å, or a conductive oxide such as ITO preferably deposited to a thickness of about 1000 - 2000Å, and more preferably to a thickness of about 1200 - 1500Å. Contact pads 21B, 21C and 21D need not be transparent, but are preferably made of the same materials deposited to a thickness which allows for low resistance conduction. If device 10 is to transmit light away from substrate 20, substrate 20 may be made of an opaque material such as silicon, or a metal foil, and contact pads 21 may be made of any conductive material regardless of whether it transmits light.

- 1) A first organic layer(s) 31 is deposited onto substrate 20 from an angle  $\theta_{\text{organic}}$  while

substrate 20 is rotating about axis 20'. Angle  $\theta_{\text{organic}}$  of step (1) is chosen such that first organic layer(s) 31 covers contact pad 21A, but does not cover contact pads 21B, 21C and 21D, and leaves sufficient clearance for subsequently deposited first electrode 32, second electrode 34 and third electrode 36 to form electrical connections with contact pads 21B, 21C and 21D, respectively. After this step, device 10 appears as in Figs. 2c and 2d.

- 2) First electrode 32 is deposited from an angle  $\theta_{\text{electrode}}$  and a direction  $\phi = \text{about } 0^\circ$  from axis 21C' while substrate 20 is held stationary. Angle  $\theta_{\text{electrode}}$  of step (2) is greater than angle  $\theta_{\text{organic}}$  of step (1) such that first electrode 32 extends past first organic layer(s) 31 and forms an electrical connection with contact pad 21B. After this step, device 10 appears as in Figs. 2e and 2f.
- 3) A second organic layer(s) 33 is deposited onto substrate 20 from an angle  $\theta_{\text{organic}}$  while substrate 20 is rotating about axis 20'. Angle  $\theta_{\text{organic}}$  of step (3) is chosen such that second organic layer(s) 34 does not cover contact pads 21C and 21D, and leaves sufficient clearance for subsequently deposited second electrode 34 and third electrode 36 to form an electrical connection with contact pads 21C and 21D, respectively. After this step, device 10 appears as in Figs. 2g and 2h.
- 4) Second electrode 34 is deposited from an angle  $\theta_{\text{electrode}}$  and a direction  $\phi = \text{about } 180^\circ$  from axis 21C' while substrate 20 is held stationary. Angle  $\theta_{\text{electrode}}$  of step (4) is greater than angle  $\theta_{\text{organic}}$  of steps (1) and (3) such that second electrode 34 extends past first organic layer(s) 31 and second organic layer(s) 33 and forms an electrical connection with contact pad 21C. After this step, device 10 appears as in Figs. 2i and 2j.
- 5) A third organic layer(s) 35 is deposited onto substrate 20 from an angle  $\theta_{\text{organic}}$  while substrate 20 is rotating about axis 20'. Angle  $\theta_{\text{organic}}$  of step (5) is chosen such that third organic layer(s) 36 does not cover contact pad 21D, and leaves sufficient clearance for subsequently deposited third electrode 36 to form an electrical connection with contact pad 21D. After this step, device 10 appears as in Figs. 2k and

2l.

6) Third electrode 36 is deposited from an angle  $\theta_{\text{electrode}}$  and a direction  $\phi = \text{about } 90^\circ$  from axis 21C' while substrate 20 is held stationary. Angle  $\theta_{\text{electrode}}$  of step (6) is greater than angle  $\theta_{\text{organic}}$  of steps (1), (3) and (5) such that third electrode 36 extends past first organic layer(s) 31, second organic layer(s) 33 and third organic layer(s) 35 and forms an electrical connection with contact pad 21D. After this step, device 10 appears as in Figs. 2m and 2n.

7) Optionally, protective layer is deposited from an angle  $\theta_{\text{protect}}$  while substrate 20 is rotating about axis 20'. Angle  $\theta_{\text{protect}}$  should be greater than angles  $\theta_{\text{organic}}$  and  $\theta_{\text{electrode}}$  of all preceding steps such that device 10 is completely covered by protective layer 38. Protective layer 38 protects device 10 from subsequent exposure to deleterious substances. Protective layer 38 should be made of a nonconductive material because it may touch more than one of contact pads 21, first electrode 32, second electrode 34, and third electrode 36. Preferably, protective layer 38 is made of teflon deposited to a thickness of approximately 2000 - 5000 Å, more preferably to a thickness of about 4000 - 5000 Å, and most preferably to a thickness of about 5000 Å. The use of a protective layer is described hereafter. After this step, device 10 appears as in Figs. 2o and 2p.

The angle " $\theta_{\text{electrode}}$ " used in forgoing process steps (2), (4) and (6) may be the same in each of the steps, or may be different. One of skill in the art is able to determine the appropriate angle  $\theta_{\text{electrode}}$  for each step depending on the desired position of the particular electrode deposited in that step. Similarly, the angle " $\theta_{\text{organic}}$ " used in forgoing process steps (1), (3) and (5) may be the same in each of the steps, or may be different, depending upon the desired position of the particular organic layer(s) deposited in that step. The deposition angle  $\theta$  may also be varied within a step to affect the geometry of the deposited organic layer(s) or electrode.

While the present embodiment describes the fabrication of a SOLED with three independently controllable emissive organic layers, i.e., first organic layer(s) 31, second organic layer(s) 33 and third organic layer(s) 35, devices with different configurations may

be fabricated. For example, by omitting steps (3) through (6), a single OLED may be fabricated. By omitting steps (5) and (6), a two color SOLED may be fabricated. By adding steps between steps (6) and (7) of the present embodiment, a four color SOLED may be fabricated, i.e., deposit an additional organic layer in accordance with step (5), and an additional electrode in accordance to step (6), but from a direction  $\phi = \text{about } 270^\circ$ , both between steps (6) and (7) of the present embodiment. The additional organic layer and electrode would result in a stack of four independently controllable OLEDs. Embodiments with different numbers of stacked OLEDs will require a different number of contact pads 21, the number of contact pads 21 required being one greater than the number of independently controllable emissive layers.

First electrode 32 and second electrode 34 should be transparent and should be thin enough to minimize the absorption of light, yet thick enough to have a low resistivity. First electrode 32 and second electrode 34 may be made of any material that is both transparent and conductive at the thickness used. Preferably, first electrode 32 and second electrode 34 are ITO/metal layers as disclosed by PCT Application WO 96/19792, which is incorporated by reference. In an embodiment where light is transmitted through third electrode 36 to a viewer, third electrode 36 is preferably made of materials and thickness preferred for first electrode 32 and second electrode 34. In an embodiment where light is transmitted through substrate 20 to a viewer, third electrode 36 is preferably made of a thick metal such as Mg/Ag, In, Ag or Au, as disclosed by PCT Application WO 96/19792, which is incorporated by reference. that reflects incident light emitted by organic layers 31, 33 and 35 back towards substrate 20 and the viewer.

First organic layer(s) 31, second organic layer(s) 33 and third organic layer(s) 35 may be made of any suitable organic light emitting material known to the art. For example, suitable organic emitting materials are described in PCT Application WO 96/19792 and United States Patent No. 5,294,870, which are incorporated by reference. Typical organic light emitting materials are transparent to light in the visible spectrum, i.e. the light emitted by organic layer(s) 31, 33 and 35, so any stacking order may be used. In the embodiment where light is transmitted through substrate 20 to a viewer, light emitted by organic layer(s) 35 passes through more layers and interfaces before reaching the viewer and may be attenuated more than light emitted by organic layer(s) 33, which in turn may be attenuated more than light emitted by organic layer(s) 31, before reaching the viewer. As a result, it is

preferred that the organic material with the most efficient emission be used in organic layer(s) 35, and that the organic material with the least efficient emission be used in organic layer(s) 31. Using the most common OLED materials, this means that it is preferred that first organic layer(s) 31 emit red light, second organic layer(s) 33 emit green light, and third organic layer(s) 35 emit blue light. However, other stacking orders can be used. If any of the organic light emitting materials used are not transparent to the light emitted by the other organic light emitting materials, the order of organic layer(s) 31, 33 and 35 should be such that the material that is not transparent does not block light emitted by other materials from reaching the viewer.

Each of first organic layer(s) 31, second organic layer(s) 33 and third organic layer(s) 35 may each comprise a single emission layer 31E, 33E and 35E, respectively, or may comprise the multiple layers of a double or single heterostructure configuration, as disclosed by Patent Application PCT WO 19792, which is incorporated by reference. Any combination of single layer, single heterostructure, or double heterostructure may be used.

Fig. 3 shows a double heterostructure configuration for first organic layer(s) 31. In the double heterostructure embodiment, first organic layer(s) 31 comprises three distinct layers, an emission layer ("EL") 31E sandwiched between a hole transport layer ("HTL") 31H and an electron transport layer ("ETL") 31T. A three color SOLED device 10 having a first organic layer(s) 31 that is double heterostructure may be fabricated by following the steps of the process for fabricating a three color SOLED device 10, wherein step 1 comprises the steps of sequentially depositing HTL 31H, EL 31E, and ETL 31T, all from an angle of about  $\theta_{\text{organic}}$  while substrate 20 is rotating about axis 20'. HTL 31H, EL 31E, and ETL 31T are transparent because of their composition and minimal thickness. Typical thicknesses for OLED layers include the following: HTL 31H may be about 50Å to 1000Å thick; EL 31E may be about 50Å to 1000Å thick; ETL 31T may be about 50Å to 1000Å thick, although variations from these ranges are possible. The lower ends of the above ranges allow optimum performance and low voltage operation. Examples of suitable organic ETL, EL, and HTL materials can be found in U.S. Patent No. 5,294,870, and PCT Application WO 96/19792, which are incorporated by reference.

If a single heterostructure, rather than a double heterostructure, configuration is used, EL 31E and ETL 31T of the double heterostructure configuration are replaced by a single multifunctional layer 31E/T as shown in Fig. 4. Alternatively, HTL 31H and EL 31E may be



replaced by a single multifunctional layer. A three color SOLED device 10 having a first organic layer(s) 31 that is single heterostructure may be fabricated by following the steps of the process for fabricating a three color SOLED device 10, wherein step 1 comprises the steps of sequentially depositing HTL 31H and EL/ETL 31E/T, all from an angle  $\theta_{\text{organic}}$  while substrate 20 is rotating about axis 20'. An example of a suitable organic multifunctional material can be found in PCT Application WO 96/19792, which is incorporated by reference. DH OLEDs often permit higher efficiencies than SH OLEDs.

In a single or double heterostructure configuration, the ordering within first organic layer(s) 31, second organic layer(s) 33, and third organic layer(s) 35 may be inverted, i.e. in a double heterostructure configuration, organic layer(s) 31 may be deposited in the order: ETL 31T, EL 31E, and HTL 31H, instead of HTL 31H, EL 31E, and ETL 31T, and in a single heterostructure configuration, organic layer(s) 31 may be deposited in the order: EL/ETL 31E/T followed by HTL 31H. An OLED with inverted layers is referred to as an organic inverted LED, or OILED. The biasing of contact pad 21A, first electrode 32, second electrode 34 and third electrode 36 should be such that an anode contacts organic layers through which holes are transported, and a cathode contacts organic layers through which electrons are to be transported, i.e., in a double heterostructure configuration that has not been inverted, contact pad 21A should be an anode, which transports electrons away from HTL 31H, and first electrode 32 should be a cathode, which transports electrons to ETL 31T.

Figs. 5a and 5b show an embodiment of the present invention in which a pixel 60, over which a device 10 will be fabricated, has contact pads 21A, 21B, 21C and 21D electrically connected to transmission pads 41, i.e., transmission pads 41A, 41B, 41C and 41D, respectively. Fig. 5b shows a cross section of Fig. 5a taken through line 5b'. The voltage at contact pads 21 is controlled by controlling the voltage at transmission pads 41, as will be discussed with reference to Fig. 6.

Fig. 6 shows an embodiment of the present invention having an array of pixels 60, over which an array of devices 10 (not shown) may be fabricated. Each pixel 60 has transmission pads 41A, 41B, 41C and 41D (contact pads 21A, 21B, 21C and 21D, are not shown in Fig. 6 for clarity, but are present as described with reference to Fig. 5).

Transmission pads 41A, 41B, 41C and 41D are electrically connected to a multiplexing controller 43 by metal lines 45 embedded in substrate 20 (not shown in Fig. 6), such that the voltage of each transmission pad 41A, 41C and 41D underneath each device 10 may be

independently controlled. Transmission pads 41B of each pixel 60 are held at a reference voltage  $V_0$ , i.e., ground. Transmission pads 41, multiplexing controller 43 and metal lines 45, may be fabricated using any means known in the art. In the embodiment where device 10 transmits light through substrate 20 to a viewer, transmission pads 41 and metal lines 45 are preferably small enough that they do not significantly affect the light transmitted to the viewer.

Figs. 7a and 7b show a three color SOLED device 1000 having more than one electrode held at the same reference voltage, i.e., ground, fabricated in accordance with an embodiment of the present invention. Fig. 7b is a cross section of Fig. 7a taken through line 7b'. A contact pad 1210A, a first organic layer(s) 1100, a first electrode 1120, a second organic layer(s) 1140, a second electrode 1160, an insulating layer 1180, a third electrode 1200, a third organic layer(s) 1220, and a fourth electrode 1240 are stacked in that order. A protective cap (not shown) similar to protective cap 38 as shown in Figs. 2o and 2p may be used to protect device 1000. First organic layer(s) 1100 is disposed between and electrically connected to contact pad 1210A and first electrode 1120. Second organic layer(s) 1140 is disposed between and electrically connected to first electrode 1120 and second electrode 1160. Insulation layer 1180 is disposed between and prevents electrical connection between second electrode 1160 and third electrode 1200. Third organic layer(s) 1220 is disposed between and electrically connected to third electrode 1200 and fourth electrode 1240. First electrode 1120 and fourth electrode 1240 are electrically connected to each other and to contact pad 1210B. Contact pad 1210B, and hence first electrode 1120 and fourth electrode 1240, are held at a reference voltage, i.e., ground. Second electrode 1160 is electrically connected to contact pad 1210C, and third electrode 1200 is electrically connected to contact pad 1210D. The voltage at contact pads 1210A, 1210C and 1210D can be independently controlled. Each of the organic layer(s) in this embodiment is therefore electrically connected between two electrodes, one of which is electrically connected to ground, and the other of which is electrically connected to a contact pad at which the voltage can be independently controlled. Light emission from first organic layer(s) 1100 occurs when a voltage is applied between contact pad 1210A, having an independently controllable voltage, and first electrode 1120, which is electrically connected to contact pad 1210B and held at ground voltage. Light emission from second organic layer(s) 1140 occurs when a voltage is applied between second electrode 1160, which is electrically connected to contact pad 1210C

having an independently controllable voltage, and first electrode 1120, which is electrically connected to contact pad 1210B and held at ground voltage. Light emission from third organic layer(s) 1220 occurs when a voltage is applied between third electrode 1200, which is electrically connected to contact pad 1210D having an independently controllable voltage, and fourth electrode 1240, which is electrically connected to contact pad 1210B and held at ground voltage. The intensity of the light emitted is determined by the magnitude of the current resulting from the applied voltage. Appropriate selection of light emitting organic materials for first organic layer(s) 1100, second organic layer(s) 1140 and third organic layer(s) 1220, allows device 1000 to emit any of various combinations of red, green and blue light by controlling the voltages on contact pads 1210A, 1210B, 1210C and 1210D.

Fig. 8 is a cross-section of a single device 100, an embodiment of the present invention, and Fig. 9 is a plan view of an array of devices 100. Fig. 8 is a cross-section of Fig. 9 at line 1'. In the interest of clarity, Fig. 9 does not depict patterning system 115 nor layers 116', 117' and 118'.

As shown in Fig. 8, device 100 comprises a substrate 111, a bottom electrode 112, an insulating strip 113, organic layer(s) 116, a top electrode 117, and a protective cap 118. Organic layer(s) 116 emit light when a voltage is applied across organic layer(s) 116 between emitting region 114 of bottom electrode 112 and top electrode 117. Protective cap 118 protects organic layer(s) 116 and top electrode 117 from exposure to deleterious substance. Light emitted from organic layer(s) 116 is typically transmitted through substrate 111 to a viewer, although light may be transmitted away from substrate 111 to a viewer if all layers deposited after organic layer(s) 116 are transparent. The emission of light from each device 100 in an array may be individually controlled using multiplexing techniques known in the art.

Patterning system 115 is used to deposit organic layer(s) 116, top electrode 117, and protective cap 118, as will be described below. Layers bearing a prime designation in Fig. 8, i.e., layers 116', 117' and 118', need not contribute to the operation of device 100, and are merely a by-product of the deposition of organic layer(s) 116, top electrodes 117 and protective caps 118, respectively.

The size and spacing of devices 100 may be determined by the intended use of the array of devices 100. For example, devices 100 with emitting regions 114 and organic layer(s) 116 less than about 100 microns by 100 microns may be used for a high resolution

display screen, while larger emitting regions 114 and organic layer(s) 116 may be used for lower resolution displays. It may be possible to fabricate emitting regions 114 and organic layer(s) 116 as small as 10 microns by 10 microns using presently available lithographic techniques, and it is contemplated that, as advances in photolithography permit smaller features and higher resolutions, the present invention could be practiced at even higher resolutions.

A process for fabricating an OLED device 100 in accordance with an embodiment of the present invention will now be described with reference to Figs. 8 and 9:

- 1) Deposit bottom electrodes 112 onto substrate 111. Substrate 111 and bottom electrodes 112 should be transparent, i.e., the material, at the thickness used, is capable of transmitting light of the wavelengths emitted by device 100, and more preferably transmitting substantially all of the light emitted. Preferably, substrate 111 is made of glass, quartz, sapphire or plastic. Bottom electrodes 112 are usually anodes, which carry electrons away from organic layers(s) 116, although bottom electrodes 112 can be cathodes. Bottom electrodes 112 can be any suitable conductive material, including indium tin oxide ("ITO"). Bottom electrodes 112 should be thin enough to minimize the absorption of light, yet thick enough to have a low resistivity. Preferably, bottom electrodes 112 are ITO, deposited to a thickness of about 200Å to 1 micron, and more preferably deposited to a thickness of about 1500Å. The patterning of bottom electrodes 112 can be done by any suitable technique, such as etching in the presence of a photoresist layer (subtractive photolithography) or by lift-off (additive photolithography). By way of example, bottom electrodes 112 can be about 50 microns in width and spaced with a period of about 150 microns, i.e., about 150 microns center-to-center.
- 2) Deposit insulating strips 113 over bottom electrodes 112. Insulating strips 113 prevent direct contact between bottom electrodes 112 on one hand and top electrodes 117 and protective caps 118 on the other. Insulating strips 113 can be any suitable insulating material, including SiO<sub>2</sub>, TiO<sub>2</sub>, SiN<sub>x</sub> or polyimide. Insulating strips 113 should be thick enough to provide adequate insulation,

but not so thick as to cause problems with subsequent processing. Preferably, insulating strips 113 are deposited to a thickness of about 1000 - 3000Å, and more preferably to a thickness of about 2000Å. The patterning of insulating strips 113 can be done by any suitable technique. The width of insulating strips 113 is determined by adding the width of insulating layer 115a, the width of overhang 115d, and allowing for an insulating patterning tolerance 113a of about 1 to 2 microns as indicated in Fig. 10. Insulating patterning tolerance 113a prevents shorting between bottom electrodes 112 and top electrodes 117 or protective caps 118. The surface of bottom electrodes 112 that remain exposed after insulating strips 113 are deposited are referred to as emitting regions 114. Emitting regions 114 can have any width larger than about 0.5 microns, and preferably have a width of about 10 to 100 microns.

- 3) Form patterning system 115 over insulating strips 113. A process for forming a patterning system 115 in accordance with a preferred embodiment of the present invention is described in detail below. Patterning system 115 has an undercut 115c, which includes undercuts 115c(1) and 115c(2), underneath overhang 115d, as illustrated in Fig. 10, which allow for the formation of protective caps 118. Patterning system 115 can be any system capable of forming undercut 115c and overhang 115d. Patterning system 115 may be a multi-layer patterning system, such as a bi- or tri-layer photoresist system. Preferably, patterning system 115 comprises an insulating layer 115a and a photoresist layer 115b. Preferably, overhang 115d should be large enough that organic layer(s) 116 do not touch patterning system 115, such that protective cap 118 may completely cover organic layer(s) 116, particularly if bi- or tri-layer photoresist system is used. It may be permissible for organic layer(s) 116 to touch insulating layer 115a. Overhang 115d preferably extends about 1 to 10 microns over insulating layer 115a, more preferably about 1 to 5 microns, and most preferably about 2 microns. As shown in Fig. 10, the extension of overhang 115d over insulating layer 115a is measured with respect to the width of that portion of insulating layer 115a where that layer contacts insulating strip 113. Overhang 115d should not completely overhang

insulating strips 113, i.e., the openings in photoresist layer 115b should be larger than emitting regions 114 by the width of insulating patterning tolerance 113a on each side.

5           4) Deposit organic light emitting layer(s) 116 over emitting regions 114 and insulating patterning tolerance 113a. Depositing organic light emitting layer(s) 116 over insulating patterning tolerance 113a prevents contact and shorting between top electrodes 117 and bottom electrodes 112. Organic light emitting layer(s) 116 may be deposited from a direction substantially perpendicular to substrate 111, such that a portion of insulating strips 113 underneath overhang 115d is not covered by deposited organic layer(s) 116 (Fig. 8).

10           5) Optionally, deposit top electrodes 117 over organic layer(s) 116. Top electrodes 117 are usually cathodes, which carry electrons to organic layers(s) 116, although top electrodes 117 can be anodes. Top electrodes 117 can be any suitable material, such as Mg, Mg/Ag, and Li/Al. Top electrodes 117 should be thick enough to have a low resistivity. Damage to organic layer(s) 116 should be avoided during the deposition of top electrodes 117 and subsequently deposited layers. For example, organic layer(s) 116 should not be heated above their glass transition temperature. Top electrodes 117 are preferably deposited to a thickness of about 50Å to 5000Å, and more preferably to a thickness of about 1000Å. Top electrodes 117 are preferably formed by thermal evaporation and preferably deposited from a direction substantially perpendicular to substrate 111. This step is optional because protective caps 118 may also serve the function of top electrodes 117, in which case top electrodes 117 would not be required.

20           6) Deposit protective caps 118, e.g., so that they completely cover electrodes 117 and organic layer(s) 116, from an angle  $\theta$  measured from a direction substantially normal to substrate 111. Angular deposition may be accomplished by any technique that allows the material of protective caps 118

to deposit into undercut 115c and completely cover organic layer(s) 116 and top electrode 117. For example, substrate 111 may be rotated by a planetary rotating mechanism under a point source positioned at an angle  $\theta$  from the normal to substrate 111. Alternatively, substrate 111 may be held stationary while protective cap 118 is deposited from an angle  $\theta$  into undercut 115c(1), and then moved to a new position where it is held stationary while protective cap 118 is deposited into undercut 115c(2), shown in Fig. 10. After protective caps 118 are deposited, top electrodes 117 and organic layer(s) 116 are completely covered and are therefore protected from subsequent exposure to deleterious substances. Preferably, protective caps 118 are formed of Al, Li/Al, Ag, Au or ITO. Protective caps 118 are preferably about 0.5 to 5 microns thick, more preferably about 0.5 to 2 microns thick, and most preferably about 1 micron thick. Protective caps 118 are preferably wider than protected electrodes 117 and organic layer(s) 116 by about 1 to 10 microns, more preferably by about 1 to 4 microns, and most preferably by about 2 microns, i.e., preferably by about 0.5 to 5 microns on each side, more preferably by about 0.5 to 2 microns on each side, and most preferably by about 1 micron on each side. The extent to which protective caps 118 are wider than organic layer(s) 116 may be limited by the height of insulating layer 115a, the angle of deposition of protective caps 118, and the width of undercut 115c. Preferably, steps (5) and (6) are performed without removing device 100 from vacuum, such that device 100 is never exposed to any potentially deleterious substance, such as air, oxygen or water vapor, until after organic layer(s) 116 are covered by protective caps 118, although device 100 may be exposed in between steps to a non-degrading environment, such as an inert gas, to facilitate the deposition of different materials or deposition from different angles.

- 7) Optionally, remove patterning system 115, and layers 116', 117' and 118' deposited on top of patterning system 115, using a suitable solvent, such as acetone. This step is referred to as "lift-off." Protective caps 118 protect organic layer(s) 116 from exposure to solvent during lift-off. Note that if a

5 patterning system 115 with an insulating layer 115a is used, as opposed to a patterning system 115 with multiple photoresist layers, insulating layer 115a will not be removed by lift-off, and will remain as a permanent part of device 100. If the optional lift-off step is not performed, layers 116', 117', and 118', as well as photoresist layer 115b, will remain, but will not contribute to the operation of device 100.

- 10 8) Optionally, deposit a passivation layer 119 over protective caps 118 to passivate the entire system. Passivation layer 119 can be any suitable material, such as  $\text{SiO}_x$ , and can be deposited by any suitable means, such as electron-beam deposition. Organic layer(s) 116 should not be heated to their glass transition temperature or above during deposition of passivation layer 119. Typical glass transition temperatures for organic layer(s) 116 include the range from about 63 °C to 150 °C. Passivation layer 119 should completely cover protective caps 118, which can be accomplished by depositing
- 15 passivation layer 119 after the optional lift-off of step (7) has been performed, or by depositing passivation layer 119 through patterning system 115 at an angle  $\theta$  greater than the angle  $\theta$  from which protective caps 118 were deposited.

20 In one embodiment, the deposition of top electrodes 117 is omitted from step (5) of the process for fabricating an OLED device 100, and protective caps 118, deposited by angular evaporation, serve as an electrode in place of top electrodes 117 as well as protecting the underlying organic layer(s) 116. In this embodiment, the material chosen for protective

25 caps 118 should be a good conductor and be able to make good electrical contact with organic layer(s) 116 as well as be able to block the penetration of deleterious substances to organic layer(s) 116. Li/Al is a preferred material for protective caps 118 in this embodiment.

30 A process for forming a patterning system 115 in accordance with a preferred embodiment of the present invention will now be described with reference to Fig. 10, which shows patterning system 115 as it appears before steps subsequent to step (3) of the process for fabricating an OLED device 100 are performed:



- 1) Deposit an insulating layer 115a over bottom electrode 112 and insulating strip 113. Insulating layer 115a is preferably deposited to a thickness of about 1 to 3 microns, and more preferably to a thickness of about 2 microns. Insulating layer 115a can be made of any insulating material that can be etched, and preferably wet etched, to form undercut 115c. For example, insulating layer 115a can be made of SiO, SiO<sub>2</sub>, or SiN<sub>x</sub> deposited by e-beam or plasma enhanced chemical vapor deposition, or polyimide deposited by spinning.
- 2) Deposit photoresist layer 115b by spinning onto insulating layer 115a to a thickness of about 1 to 3 microns, preferably 1 to 2 microns. A photoresist thickness from the lower end of the range should be chosen when smaller features, i.e., 10 micron wide organic layer(s) 116, are to be fabricated. Photoresist layer 115b can be made of a photoresist such as AZ4210 or AZ4110, from Hoechst Celanese Corporation, for example.
- 3) Soft bake photoresist layer 115b at a temperature and time which depend on the material of photoresist layer 115b and the baking method. For example, if AZ4210 is used, the soft bake may be for 3 minutes at 105 °C on a hot plate.
- 4) Expose photoresist layer 115b over emitting regions 114, using a mask having an exposure larger than emitting regions 114, and develop. While it is possible to use a positive photoresist as described, i.e., a photoresist that can be removed by developer only where exposed to radiation, it is also possible to practice the present invention using a negative photoresist, i.e., a photoresist that can be removed in developer only where not exposed to radiation, by using a different mask. After developing, photoresist layer 115b may be post-baked to increase resistivity to wet etchants and adhesion to insulating layer 115a. Post-bake time, temperature and method depend on the particular photoresist and etchants involved. In the case of AZ4210 photoresist and BOE etchant, a post-bake at about 105 °C for about 3 to 10 minutes on a hot plate may be used.

- 5) Wet etch insulating layer 115a, forming undercut 115c and overhang 115d. By controlling the etch temperature, etch time, etchant concentration, etchant stir speed, the thickness to which insulating layer 115a is deposited, and the method used to deposit insulating layer 115a, the size of undercut 115c can be controlled. For example, 70 ml buffered oxide etchant, such as BOE (10:1), i.e., 36.5% (w/w) ammonium fluoride, 4.5% (w/w) hydrofluoric acid, and 59% (w/w) deionized water, available from J.T. Baker, mixed with 5 ml hydrofluoric acid (49% in deionized water) can be used at 20 °C for 4.5 minutes at a stir speed of 400 rpm to etch a 2 micron thick SiO<sub>2</sub> insulating layer 115a deposited by plasma enhanced chemical vapor deposition to form a 10 micron undercut 115c, which also results in a 10 micron overhang 115d. A smaller undercut 115c of 2 microns can be obtained by using buffered oxide etchant at 21 °C for 8 minutes with no stir on a 1.7 micron thick SiO<sub>2</sub> insulating layer 115a deposited by electron beam evaporation. Preferably, the etchant used to etch insulating layer 115a etches insulating strips 113 or bottom electrodes 112 only minimally, and more preferably does not etch insulating strips 113 or bottom electrodes 112 at all. For example, if buffered oxide etchant is used to etch insulating layer 115a, it is preferred that insulating strips 113 are sputter deposited TiO<sub>2</sub> or polyimide deposited by spin coating. Note that insulating layer 115a of patterning system 115 may not be removed by the optional lift-off step, but photoresist layer 115b, as well as layers 116', 117' and 118', can be removed.

Alternatively, patterning system 115 may be a bi-layer or tri-layer photoresist system with an undercut. Bi-layer and tri-layer photoresist systems are disclosed in M. Hatzakis, "Multilayer resist Systems for Lithography", Solid State Technology, August 1981, pp. 74-80; E. Ong and E.L. Hu, "Multilayer Resists for Fine Line Optical Lithography", Solid State Technology, June 1984; J.M Moran and D.J. Magdan, J. Vac. Sci. Tech. 16, 1620 (1979), which are incorporated by reference. However, patterning system 115 with an insulating layer 115a facilitates the formation an undercut 115c larger than about 1 micron and is therefore preferred over tri-layer and bi-layer photoresist systems. Other methods of forming a patterning system 115 with an undercut 115c may also be suitable for use in the present

invention.

A process for fabricating a stack of devices 100 in accordance with an embodiment of the present invention will now be described with reference to Fig. 11:

- 5           1)     Fabricate a device 100R as described in the process for fabricating an OLED device 100, with organic layer(s) 116(R) capable of emitting red light. All layers of device 100R through which light is to be transmitted should be transparent, including optional top electrodes 117 and protective caps 118, such that light from subsequently deposited devices 100 can be transmitted  
10           through device 100R. For this reason, ITO is a preferred material for protective cap 118.
- 2)     Deposit a separation layer 121 over the device 100R fabricated in step (1). Separation layer 121 can be made of any transparent insulating material, such  
15           as SiO<sub>x</sub>, SiN<sub>x</sub>, or Al<sub>2</sub>O<sub>3</sub>.
- 3)     Fabricate device 100G as described in the process for fabricating an OLED device 100, with organic layer(s) 116(G) capable of emitting green light, on  
20           top of separation layer 121, i.e., separation layer performs the function of substrate 111. Similar to device 100R, all layers of device 100G should be transparent.
- 4)     Repeat steps (2) and (3), fabricating device 100B, with organic layer(s)  
25           116(B) capable of emitting blue light, instead of device 100G. Top electrode 117 and protective cap 118 of device 100B, the final device 100 to be deposited, need not be transparent, and may be reflective to enhance the intensity of light transmitted through substrate 111 to a viewer.

30     The conditions under which devices 100 are fabricated should be such that organic layer(s) 116 of previously deposited devices 100 are not damaged. For example, organic layer(s) 116 should not be heated above their glass transition temperatures. As a result, it may be necessary to select organic layer(s) 116 of with a high glass transition temperature

and photoresists used in patterning system 115 with a low bake temperature.

Alternatively, protective layer 118 of a previously deposited device 100, such as device 100R, can serve as bottom electrode 112 of a subsequently deposited device 100, such as device 100G. In this embodiment, the insulating protective layers 121 are not necessary.

5 As shown in Fig. 11, each device 100 in the stack can contain different materials in organic layer 116, and can emit different colors. For example, a red OLED device 100R with red emitting OLED layer(s) 116(R) can be fabricated as described above, then a green OLED device 100G with green emitting OLED layer(s) 116(G), then a blue OLED device 100B with blue emitting OLED material 116(B), all separated by separation layers 121, as shown  
10 in Fig. 11, to form a multi-color stack. Alternatively, each of the devices 100 in the stack may have the same EL material in OLED layer 116 in order to enhance intensity. The order of stacking in the latter embodiment is not critical, because each device 100R, 100G and 100B may be transparent to the light emitted by the other OLED devices 100. Factors that may influence the preferred stacking order include: transparency to the light emitted by other  
15 devices 100, i.e., put the more transparent devices 100 closer to the viewer; robustness, i.e., fabricate the least robust devices 100 last to reduce the chance of damage during subsequent processing; and brightness, i.e. put the devices 100 with the least intense emission closer to the viewer.

A preferred method of stacking OLED devices 100 is disclosed above, with with  
20 reference to Figures 1 to 7.

In the various embodiments of the present invention, organic layer(s) 116 can be a single layer, or can comprise the multiple layers of a double or single heterostructure configuration, as shown in Figs. 12 and 13, respectively. For simplicity, organic layer(s) 116 are shown as a single layer in the Figs., other than Figs. 12 and 13, even though there may  
25 actually be multiple sub-layers. If, for example, a double heterostructure OLED is used in the present invention, organic layer(s) 116 will consist of an emission layer ("EL") 116E sandwiched between an hole transport layer ("HTL") 116H and an electron transport layer ("ETL") 116T as shown in Fig. 12. A double heterostructure OLED may be fabricated by following the steps of the process for fabricating an OLED device 100, wherein step (4)  
30 comprises the steps of sequentially depositing HTL 116H, EL 116E, and ETL 116T; all from a direction substantially perpendicular to substrate 111. HTL 116H, EL 116E, and ETL 116T are transparent because of their composition and thickness. Typical thicknesses for OLED

layers include the following: HTL 116H may be about 50Å to 1000Å thick; EL 116E may be about 50Å to 1000Å thick; ETL 116T may be about 50Å to 1000Å thick, although variations from these ranges are possible. The lower ends of the above ranges allow optimum performance and low voltage operation. Examples of suitable organic ETL, EL, and HTL materials can be found in U.S. Patent No. 5,294,870, and PCT Application WO 96/19792, which are incorporated by reference.

If a single heterostructure, rather than a double heterostructure, OLED structure is used, EL 116E and ETL 116T are replaced by a single multifunctional layer 116E/T as shown in Fig. 13. A single heterostructure OLED may be fabricated by following the steps of the process for fabricating an OLED device 100, wherein step (4) comprises the steps of sequentially depositing HTL 116H and EL/ETL 116E/T, all from a direction substantially perpendicular to substrate 111. An example of suitable organic multifunctional materials can be found in PCT Application WO 96/19792, which is incorporated by reference. Double heterostructure OLEDs generally permit higher efficiencies than single heterostructure OLEDs.

In a single or double heterostructure configuration, the ordering within organic layer(s) 116 may be inverted, i.e. in a double heterostructure configuration, organic layer(s) 116 may be deposited in the order: ETL 116T, EL 116E, and HTL 116H, instead of HTL 116H, EL 116E, and ETL 116T, and in a single heterostructure configuration, organic layer(s) 116 may be deposited in the order: EL/ETL 116 E/T followed by HTL 116H. An OLED with inverted layers is referred to as an organic inverted LED, or OILED. The biasing of bottom electrodes 112 and top electrodes 117 should be such that an anode contacts organic layers through which holes are transported, and a cathode contacts organic layers through which electrons are to be transported, i.e., in a double heterostructure configuration that has not been inverted, bottom electrode 112 should be an anode, which transports electrons away from HTL 116H, and top electrode 117 should be a cathode, which transports electrons to ETL 116T.

The organic emissive layer 116E of the present invention can be any suitable OLED material, and can emit light of any wavelength. Suitable organic emitting materials are described in PCT Application WO 96/19792 and United States Patent No. 5,294,870, which are incorporated by reference.

As shown in Fig. 14, a colored down conversion phosphor layer 170 may optionally

be included between organic layer(s) 116 and substrate 111, preferably between bottom electrode 112 and substrate 111, for down conversion of the light emitted from the OLED emission layer to a desired color. Down conversion phosphor layer 170 may also be deposited on either side of substrate 111. For example, a blue OLED layer 116(B) may emit blue light, which is converted down to red light by down conversion phosphor layer 170.

The embodiment shown in Fig. 14 is designed to produce monochromatic red light emission. The device of 100 Fig. 14 may be fabricated by depositing and patterning down conversion phosphor layer 170 onto substrate 111 using any suitable technique, and then following the steps of the process for fabricating an OLED device 100. Green and red down conversion phosphors are known in the art, as disclosed by U.S. Patent No. 5,294,870 to Tang, which is incorporated by reference.

The present invention includes monochrome products comprising an array of pixels, wherein each pixel comprises a number of devices 100 that emit the same or substantially the same colors of light fabricated next to each other, as well as multi-color products comprising an array of pixels, wherein each pixel comprises a number of devices 100 that emit different colors of light fabricated next to each other.

A pixel of a multi-color product could comprise three devices 100, side by side, that emit red, green, and blue light respectively. For example, the different color emissions could be achieved by using different down conversion phosphor layers 170. Such a product could be fabricated by depositing a pattern of green and red down conversion phosphor layers 170 onto substrate 111 using any suitable technique, and then following the steps of the process for fabricating an OLED device 100 to fabricate an array of blue emitting OLED devices 100 on top of the pattern of down conversion phosphor layers 170, such that some of the devices 100 would transmit blue light that is not converted, some of the devices 100 would transmit blue light that is converted to green light, and some of the devices 100 would transmit blue light that is converted to red light.

Alternatively, a pixel of side by side devices 100 that emit different colors could be fabricated using different materials for the organic layer(s) 116 of each device in accordance with an embodiment of the present invention according to the following process:

- 1) Fabricate an array of OLED devices 100 according to the process for fabricating an OLED device 100, including lift-off, that emit a particular color

of light, blue for example, leaving spaces in between the devices 100. Protective caps 118 will protect devices 100 fabricated in the present step during subsequent processing.

5                   2)     Fabricate an array of OLED devices 100 that emit a different color of light, green for example, in the spaces left during step (1) of the present process, still leaving some space. Use the process for fabricating an OLED device 100, including lift-off, but start with step (3) of that process, because bottom electrodes 112 and insulating strips 113 are already present from step (1) of the present process. If a patterning system having an insulating layer 115a was used during step (1) of the present process, the existing insulating layer 115a may be used during step (3) of the process for fabricating an OLED device 100. Protective caps 118 will protect devices 100 fabricated in the present step during subsequent processing.

10  
15                   3)     Repeat step (2) of the present process, fabricating an array of devices 100 that emit yet another color of light, red for example, in the remaining space.

During each step, the processing conditions should be such that previously fabricated  
20     OLEDs are not damaged.

The present invention may also be used to fabricate transparent OLEDs. A device 100 that is transparent would be well suited for use in a heads-up display, for example on a windshield for a car, or a visor for a motorcycle or airplane helmet. Transparent OLED devices 100 can also be stacked for multi-color products or to enhance intensity. All layers  
25     should be transparent to visible light in a transparent OLED. A device 100 that is transparent is also well suited for high contrast applications. High contrast is achieved by placing a background 175 made of an optically absorbent material next to device 100, as shown in Fig. 15. Light incident upon device 100 from external sources passes through device 100 and is absorbed by background 175, reducing the reflection of light from external sources to the  
30     viewer.

In one embodiment, the present invention may be used to fabricate a device 100 designed to emit light to a viewer situated on the same side of substrate 111 as device 100.

Substrate 111 need not be transparent in this embodiment, and a reflective layer may be deposited onto substrate 111 prior to the fabrication of device 100 in order to reflect light incident upon substrate 111 back towards the viewer. However, top electrode 117, protective cap 118, and any passivation layer 119 should be transparent.

5           The light emitting devices 100 of the present invention can optionally comprise a loss limiting layer 180 of low-loss, high refractive index dielectric material, such as  $\text{TiO}_2$ , beneath bottom electrodes 112, as shown in Fig. 16. A loss limiting layer 180 is especially preferred when bottom electrodes 112 are made from ITO, which is a high-loss material. Without loss limiting layer 180, light from organic layer(s) 116 can be easily waveguided in and absorbed by bottom electrodes 112. The refractive indexes for  $\text{TiO}_2$  and ITO are about 2.6 and 2.2, respectively. Loss limiting layer 180 therefore substantially eliminates waveguiding and absorption in the ITO. A device 100 with a loss limiting layer can be fabricated by depositing and patterning loss limiting layer 180 onto substrate 111 using any suitable technique, and then following the steps of the process for fabricating an OLED device 100.

10           The deposition techniques for any of the above-listed methods are well known in the art. For example, a preferred method of depositing the organic layers is by thermal evaporation; a preferred method of depositing metal layers is by thermal or electron-beam evaporation; a preferred method of depositing ITO is by electron-beam evaporation or sputtering; a preferred method of depositing phosphor layers is by thermal evaporation; and a preferred method of depositing dielectrics is by plasma-enhanced chemical vapor deposition, sputtering or electron-beam evaporation. However, the present invention contemplates the use of any method of depositing layers of material suitable for use with a patterning system.

15           The present invention can be used in a wide variety of consumer products, including computers, televisions, telecommunications products with a display component, vehicles, billboards, signs, large area wall, theatre, stadium screens, xerography, heads-up displays for windshields and helmet visors, and video games.

#### Example

20           A row of devices 100 was fabricated in accordance with the process for fabricating an OLED device 100, as will now be described with reference to Fig. 8:

- 1)       A glass substrate 111 pre-coated with bottom electrode 112, which is made of



ITO about 1600Å thick, was obtained. A suitable glass pre-coated with ITO is obtainable from Donnelly Applied Films Corporation. The present example describes the fabrication of a single row of devices 100, not an array, and a single bottom electrode 112, which is not patterned, covers substantially all of substrate 111. Substrate 111 with bottom electrode 112 was cleaned as follows: (a) submersed in a cleaning solution such as Tergitol, from J.T. Baker Inc., and deionized water, with ultrasonic agitation, (b) rinsed in deionized water, (c) boiled in 1,1,1-trichlorethane, acetone and 2-propanol. At the end of each step, substrate 111 was dried with a filtered N<sub>2</sub> gun.

- 2) Insulating strips 113 were deposited to a thickness of about 2000Å, made of dilute Probimide 285, which is a polyimide available from Olin Microelectronic Materials. First, an adhesion promoter, which was 1 part by volume QZ3289 and 9 parts QZ3290, both available from Olin Microelectronic Materials, was spun on. Then, a solution of 2 parts by volume Probimide 285 in 1 part by volume 4-butyrolactone was spun on. Insulating strips 113 were then cured. Insulating strips 113 were next patterned using standard photolithographic techniques to define emitting regions 114 that were 300 microns wide x 1.5 mm. long with a period of 500 microns, i.e., separated by 200 micron wide insulating strips 113.

- 3) Insulating layer 115a, made of SiO<sub>2</sub>, was deposited to a thickness of about 2 microns using plasma enhanced chemical vapor deposition (PECVD). Photoresist layer 115b, made of AZ4210 photoresist, was deposited to a thickness of about 2 microns. Photoresist layer 115b was patterned by exposing to radiation through a mask with slots 1 cm long (any length greater than the 1.5 mm length of insulating strips 113 would work) and 400 microns wide with a period of 500 microns, with the slots centered above emitting regions 114, and developing in AZ400K, a developer available from Hoechst Celanese Corporation, diluted 1:4 in deionized water. The patterning left 100 micron wide photoresist layers 115b centered over 200 micron wide insulating strips 112.

- 4) Insulating later 115a was wet etched in a mixture of 200 ml BOE (10:1) and 20 ml hydrofluoric acid (49% in deionized water) at about 21 °C, for about 3.4 minutes at a stir speed of about 100 rpm.
- 5) Organic layer(s) 116 were deposited from a direction substantially perpendicular to substrate 111. Organic layers 116 were deposited in the single heterostructure configuration of Fig. 13, with a hole transport layer 116H, made of  $\alpha$ -NPD (4,4'-bis[N-(1-naphthyl)-N-phenyl-amino]biphenyl) deposited to a thickness of 400Å, and a multifunctional layer 116E/T, made of Alq<sub>3</sub> (tris(8-hydroxyquinoline) aluminum) deposited to a thickness of about 600Å.
- 6) Top electrode 117 was deposited from a direction substantially perpendicular to substrate 111. Top electrode 117 was a cathode formed by thermal co-evaporation of Mg:Ag (atomic ratio 24:1) to a thickness of 250Å followed by thermal evaporation of Ag to a thickness of 200Å.
- 7) Protective cap 118, made of Ag, was deposited by thermal evaporation to a thickness of 1 micron from an angle  $\theta$  of 45°. With reference to Fig. 10, 0.5 microns were first deposited into undercut 115c(1), and then 0.5 microns were deposited into undercut 115c(2), while substrate 111 was held stationary, to completely cover top electrode 117 and organic layers 116.
- 8) Photoresist layer 115b, as well as layers 116', 117' and 118', were removed ("lifted-off") by soaking in acetone for 3 minutes and drying under an N<sub>2</sub> gun.

Fig. 17a is an optical micrograph of a row of devices 100 fabricated according to the foregoing process. Insulating layers 115a and protective caps 118 are clearly visible.

Fig. 17b shows I-V plots for a row of devices 100. Plot 131 shows an I-V plot for devices 100 before the lift-off step (8) was performed. Plot 132 shows an I-V plot for the same devices after lift-off step (8) was performed. Comparing plots 131 and 132, it can be

seen that there is no degradation of the I-V curve due to lift-off, again demonstrating that the acetone did not penetrate protective cap 118 during lift-off. Some devices 100 were electrically connected to each other before lift-off, while all devices 100 were electrically isolated after lift-off, suggesting that dangling pieces of layers 116', 117' or 118' may have been connecting some devices 100 prior to lift-off.

Fig. 17c shows plots of intensity of light output v. current for the same row of devices 100 used to generate Fig. 17b. Comparing plot 133, generated before lift-off, and plot 134, generated after lift-off, it can be seen that there is no degradation of light output characteristics due to lift-off, demonstrating that acetone did not penetrate protective cap 118 during lift-off.

The present invention may also be used to fabricate transparent OLEDs (TOLEDs), where the entire device is transparent to visible light. Such a device would be well suited for use in a heads up display, for example on a windshield for a car, a visor for a motorcycle or airplane helmet, or a cockpit window. TOLED devices can also be stacked to enhance intensity.

In one embodiment, the present invention may also be used to fabricate an organic device 10 designed to emit light to a viewer on the same side of substrate 20 as device 10. Substrate 20 need not be transparent in this embodiment, and a reflective layer may be deposited onto substrate 20 prior to the fabrication of device 10 in order to reflect light incident upon substrate 20 back towards the viewer. However, third electrode 36 and protective cap 38 should be transparent, and a reflective layer should not be deposited after third electrode 36. Also, it is preferable that the ordering of the colors of organic layer(s) 31, 33 and 35 should be reversed, i.e. that first organic layer(s) 31 emit red, second organic layer(s) 33 emit green, and third organic layers(s) emit blue, because in this embodiment, the last deposited layers will be closest to the viewer, not the first deposited layers.

The deposition techniques for any of the above-listed methods are well known in the art. For example, a preferred method of depositing the organic layers is by thermal evaporation; a preferred method of depositing metal layers is by thermal or electron-beam evaporation; a preferred method of depositing ITO is by electron-beam evaporation or sputtering. However, the present invention contemplates the use of any method of depositing layers of material suitable for use with a photoresist system.

The present invention can be used in a wide variety of consumer products, including computers, televisions, telecommunications devices with a display component, vehicles, billboards, signs, large area wall, theatre, and stadium screens, xerography, heads up displays for windshields, cockpits and helmet visors, and video games.

5       The subject invention as disclosed herein may be used in conjunction with co-pending applications: "High Reliability, High Efficiency, Integratable Organic Light Emitting Devices and Methods of Producing Same", Serial No. 08/774,119 (filed December 23, 1996); "Novel Materials for Multicolor LED's", Serial No. 08/850,264 (filed May 2, 1997); "Electron Transporting and Light Emitting Layers Based on Organic Free Radicals", Serial  
10       No. 08/774,120 (filed December 23, 1996); "Multicolor Display Devices", Serial No. 08/772,333 (filed December 23, 1996); "Red-Emitting Organic Light Emitting Devices (LED's)", Serial No. 08/774,087 (filed December 23, 1996); "Driving Circuit For Stacked Organic Light Emitting Devices", Serial No. 08/792,050 (filed February 3, 1997); "High Efficiency Organic Light Emitting Device Structures", Serial No. 08/772,332 (filed  
15       December 23, 1996); "Vacuum Deposited, Non-Polymeric Flexible Organic Light Emitting Devices", Serial No. 08/789,319 (filed January 23, 1997); "Displays Having Mesa Pixel Configuration", Serial No. 08/794,595 (filed February 3, 1997); "Stacked Organic Light Emitting Devices", Serial No. 08/792,046 (filed February 3, 1997); "High Contrast Transparent Organic Light Emitting Device Display", Serial No. 08/821,380 (filed March 20,  
20       1997); "Organic Light Emitting Devices Containing A Metal Complex of 5-Hydroxy-Quinoxaline as A Host Material", Serial No. 08/838,099 (filed April 15, 1997); "Light Emitting Devices Having High Brightness", Serial No. 08/844,353 (filed April 18, 1997); "Organic Semiconductor Laser", Serial No. 60/046,061 (filed May 9, 1997); "Organic Semiconductor Laser", Serial No. 08/859,468 (filed May 19, 1997); "Saturated Full Color Stacked Organic Light Emitting Devices", Serial No. 08/858,994 (filed May 20, 1997); "An  
25       Organic Light Emitting Device Containing a Hole Injection Enhancement Layer", Serial No. 08/865,491 (filed May 29, 1997); "Plasma Treatment of Conductive Layers", Serial No. PCT/US97/10252; (filed June 12, 1997; Patterning of Thin Films for the Fabrication of Organic Multi-Color Displays", Serial No. PCT/US97/10289 (filed June 12, 1997); "Double  
30       Heterostructure Infrared and Vertical Cavity Surface Emitting Organic Lasers", Serial No. 60/053,176 (filed July 18, 1997); "Oleds Containing Thermally Stable Asymmetric Charge Carrier Materials", Serial No. 08/929,029 filed (September 8, 1997), "Light Emitting Device

with Stack of Oleds and Phosphor Downconverter", Serial No. 08/925,403 (filed September 9, 1997), "An Improved Method for Depositing Indium Tin Oxide Layers in Organic Light Emitting Devices", Serial No. 08/928,800 (filed September 12, 1997), "Azlactone-Related Dopants in the Emissive Layer of an Oled" (filed October 9, 1997), Serial No. 08/948,130,  
5 "A Highly Transparent Organic Light Emitting Device Employing A Non-Metallic Cathode", (filed November 3, 1997), Attorney Docket No. 10020/40 (Provisional), "A Highly Transparent Organic Light Emitting Device Employing a Non-Metallic Cathode", (filed November 5, 1997), Attorney Docket No. 10020/44, and "Low Pressure Vapor Phase Deposition of Organic Thin films" (filed November 17, 1997), Attorney Docket No.  
10 10020/37, each co-pending application being incorporated herein by reference in its entirety. The subject invention may also be used in conjunction with the subject matter of each of co-pending U.S. patent application Serial Nos. 08/354,674, 08/613,207, 08/632,322 and 08/693,359 and provisional patent application Serial Nos. 60/010,013, 60/024,001 and 60/025,501, each of which is also incorporated herein by reference in its entirety.

15 Those with skill in the art may recognize various modifications to the embodiments of the invention described and illustrated herein. Such modifications are meant to be covered by the spirit and scope of the appended claims.

What is claimed is:

- 1 1. A method of fabricating an organic thin film device, comprising the steps of:
  - 2 a. creating a patterning system having an insulation layer and a photoresist layer
  - 3 with a photoresist overhang on a substrate having a plurality of contact pads;
  - 4 b. depositing through the patterning system a first electrode that electrically
  - 5 connects to a first contact pad of said plurality of contact pads;
  - 6 c. depositing through the patterning system a organic layer that significantly
  - 7 overlaps and electrically connects to the first electrode; and
  - 8 d. depositing through the patterning system a second electrode that significantly
  - 9 overlaps and electrically connects to the first organic layer, and electrically
  - 10 connects to a second contact pad of said plurality of contact pads.
- 1 2. The method of claim 1, wherein the voltage at each contact pad can be independently
- 2 controlled.
- 1 3. The method of claim 2, wherein the voltage at one of the contact pads is set to a
- 2 ground voltage.
- 1 4. The method of claim 1, wherein the organic layer comprises an organic emission
- 2 layer.
- 1 5. The method of claim 1, wherein the organic layer comprises an organic emission
- 2 layer electrically connected to an organic hole transport layer.
- 1 6. The method of claim 1, wherein the organic layer comprises an organic emission
- 2 layer electrically connected between an organic hole transport layer and an organic
- 3 electron transport layer.
- 1 7. The method of claim 1, further comprising the step of depositing a loss limiting layer
- 2 prior to said step of depositing an organic layer.

1 8. The method of claim 1, further comprising the step of depositing a protective cap after  
2 said step of depositing an organic layer.

1 9. A method of fabricating a stacked organic thin film device, comprising the steps of:  
2 a. creating a patterning system having an insulation layer and a photoresist layer  
3 with a photoresist overhang on a substrate having a first contact pad, a second  
4 contact pad, a third contact pad, and a fourth contact pad;  
5 b. depositing through the patterning system a first organic layer that covers and  
6 electrically connects to the first contact pad;  
7 c. depositing through the patterning system a first electrode that electrically  
8 connects to the second contact pad, and significantly overlaps and electrically  
9 connects to the first organic layer;  
10 d. depositing through the patterning system a second organic layer that  
11 significantly overlaps and electrically connects to the first electrode;  
12 e. depositing through the patterning system a second electrode that electrically  
13 connects to the third contact pad, and significantly overlaps and electrically  
14 connects to the second organic layer;  
15 f. depositing through the patterning system a third organic layer that  
16 significantly overlaps and electrically connects to the second electrode; and  
17 g. depositing through the patterning system a third electrode that electrically  
18 connects to the fourth contact pad, and significantly overlaps and electrically  
19 connects to the third organic layer.

1 10. The method of claim 9, wherein the first, second and third organic emission layers are  
2 deposited while the substrate is rotating from angles  $\theta_{\text{organic1}}$ ,  $\theta_{\text{organic2}}$ , and  $\theta_{\text{organic3}}$ ,  
3 respectively, as measured from an axis substantially normal to the substrate, and the  
4 first, second and third electrodes are deposited while the substrate is stationary from  
5 angles  $\theta_{\text{electrode1}}$ ,  $\theta_{\text{electrode2}}$ , and  $\theta_{\text{electrode3}}$ , respectively, as measured from the axis  
6 substantially normal to the substrate, and wherein angle  $\theta_{\text{electrode1}}$  is larger than angle  
7  $\theta_{\text{organic1}}$ , angle  $\theta_{\text{electrode2}}$  is larger than angles  $\theta_{\text{organic1}}$  and  $\theta_{\text{organic2}}$ , and angle  $\theta_{\text{electrode3}}$  is  
8 larger than angles  $\theta_{\text{organic1}}$ ,  $\theta_{\text{organic2}}$ , and  $\theta_{\text{organic3}}$ .

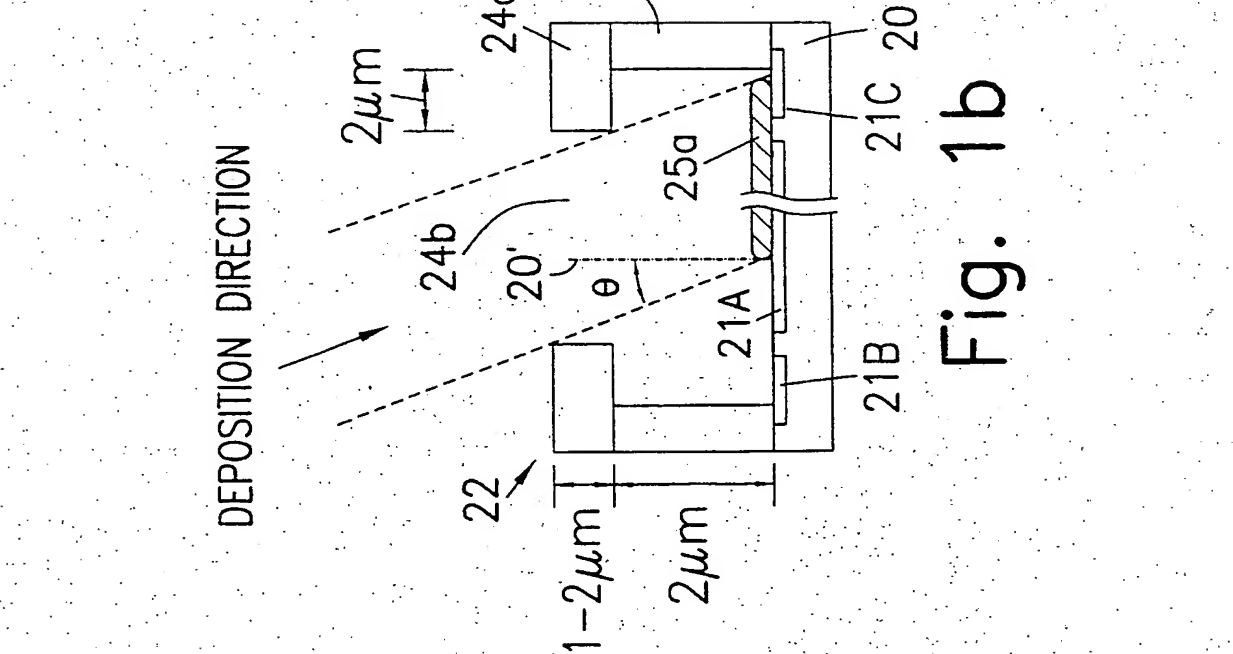
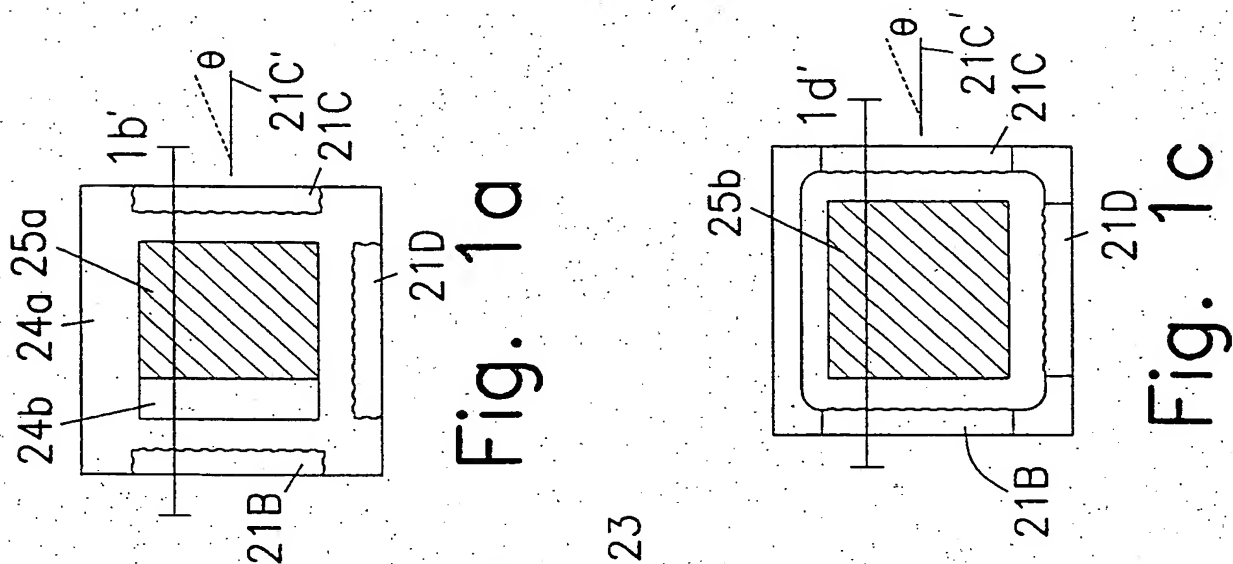
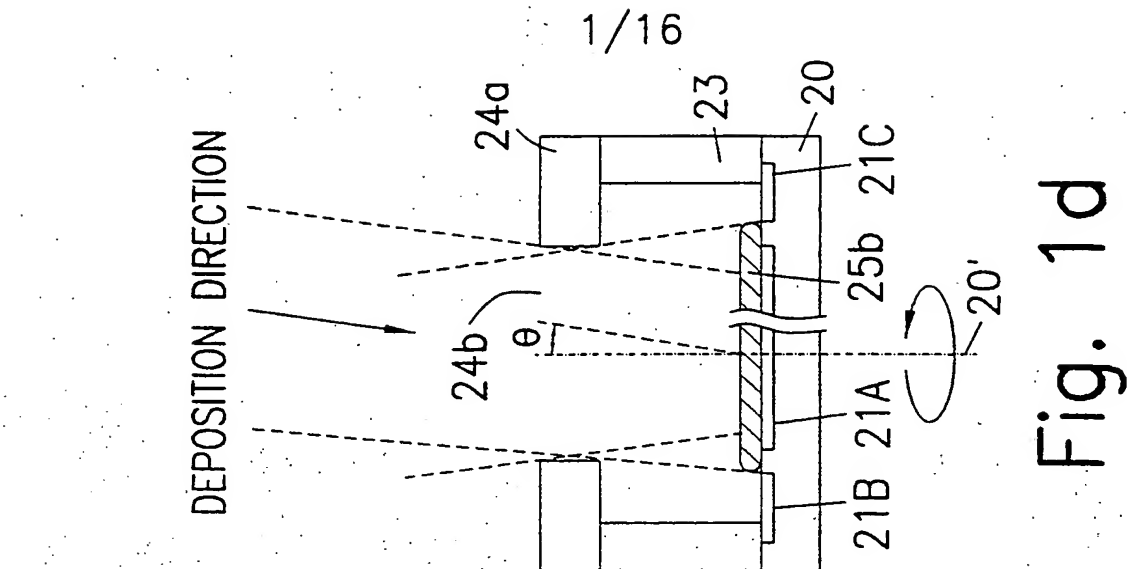
- 1 11. A method of fabricating a stacked organic thin film device, comprising the steps of:
- 2 a. creating a patterning system having an insulation layer and a photoresist layer
- 3 with a photoresist overhang on a substrate having a first contact pad, a second
- 4 contact pad, a third contact pad, and a fourth contact pad;
- 5 b. depositing through the patterning system a first organic layer that covers and
- 6 electrically connects to the first contact pad;
- 7 c. depositing through the patterning system a first electrode that electrically
- 8 connects to the second contact pad, and significantly overlaps and electrically
- 9 connects to the first organic layer;
- 10 d. depositing through the patterning system a second organic layer that
- 11 significantly overlaps and electrically connects to the first electrode;
- 12 e. depositing through the patterning system a second electrode that electrically
- 13 connects to the third contact pad, and significantly overlaps and electrically
- 14 connects to the second organic layer;
- 15 f. depositing through the patterning system an insulating layer on top of the
- 16 second electrode;
- 17 g. depositing through the patterning system a third electrode on top of the
- 18 insulating layer that electrically connects to the fourth contact pad, and is
- 19 electrically insulated from the second electrode by the insulating layer;
- 20 h. depositing through the patterning system a third organic layer that
- 21 significantly overlaps and electrically connects to the third electrode; and
- 22 i. depositing through the patterning system a fourth electrode that electrically
- 23 connects to the second contact pad, and significantly overlaps and electrically
- 24 connects to the third organic layer.

- 1 12. The method of claim 11, wherein the stacked organic light emitting device is
- 2 transparent.

- 1 13. The method of claim 11, wherein the first organic emission layer is a blue emitting
- 2 organic layer, the second organic emission layer is a green emitting organic layer, and
- 3 the third organic emission layer is a red emitting organic layer.



- 1 14. The method of claim 1, wherein the method is used to fabricate a consumer product.
- 1 15. The method of claim 14, wherein the method is used to fabricate a consumer product  
2 selected from the group consisting of: a computer, a television, a billboard, a sign, a  
3 vehicle, a printer, a telecommunications device, a telephone, and a copier.
- 1 16. The method of claim 1, wherein the method is used to fabricate an array of stacked  
2 organic light emitting devices.
- 1 17. The method of claim 9, wherein the method is used to fabricate an array of stacked  
2 organic light emitting devices.
- 1 18. The method of claim 11, wherein the method is used to fabricate an array of stacked  
2 organic light emitting devices.
- 1 19. The method of claim 1, further comprising the step of depositing a down conversion  
2 phosphor layer.
- 1 20. The method of claim 1, further comprising the step of depositing a loss limiting layer.
- 1 21. The method of claim 1, wherein the substrate is put under vacuum prior to step (b),  
2 and is not removed from vacuum until after step (d) has been completed.
- 1 22. An apparatus for carrying out the method of claim 1.
- 1 23. A device fabricated in accordance with the method of claim 1.



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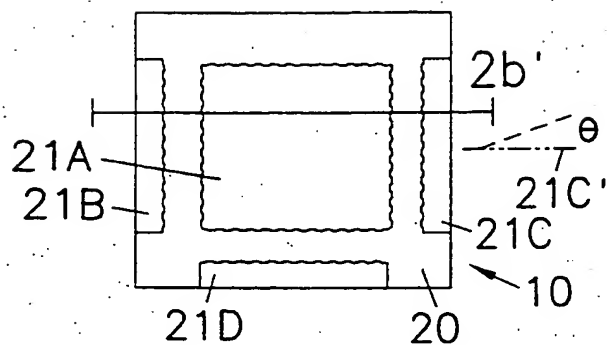


Fig. 2a

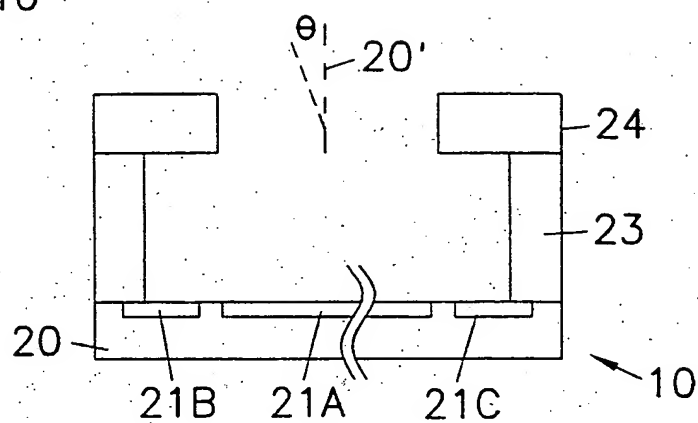


Fig. 2b

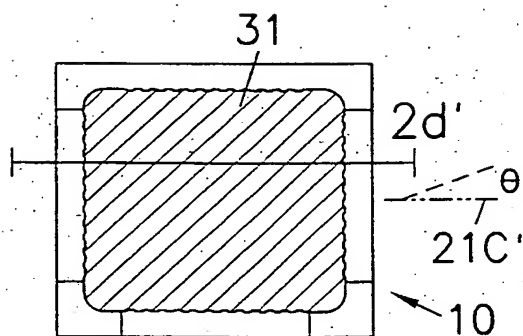


Fig. 2c

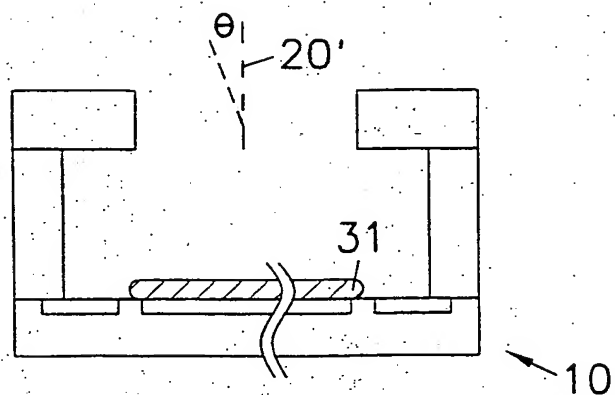


Fig. 2d

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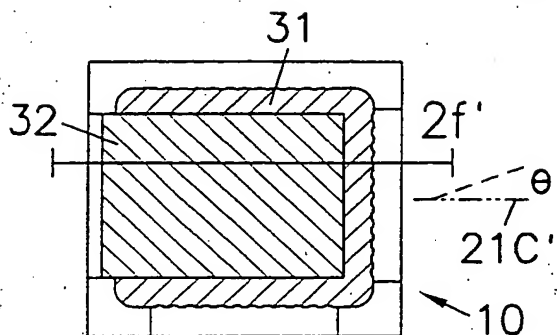


Fig. 2e

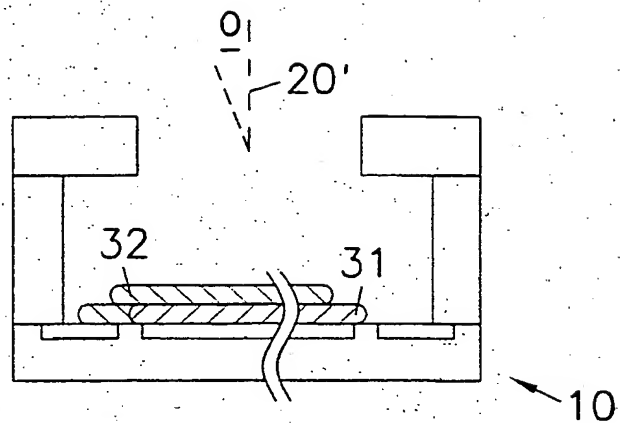


Fig. 2f

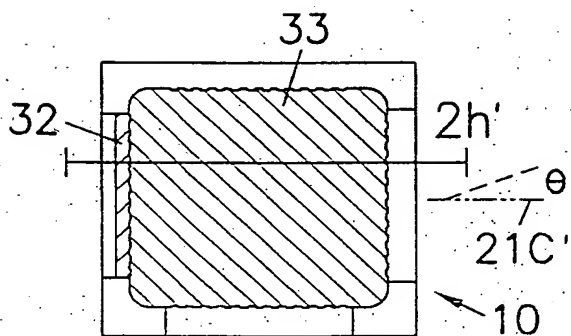


Fig. 2g

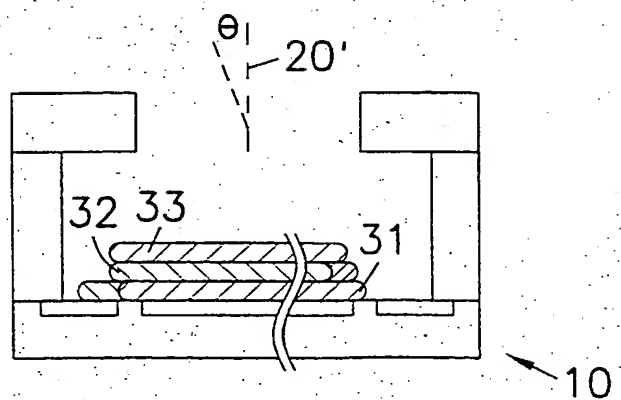


Fig. 2h

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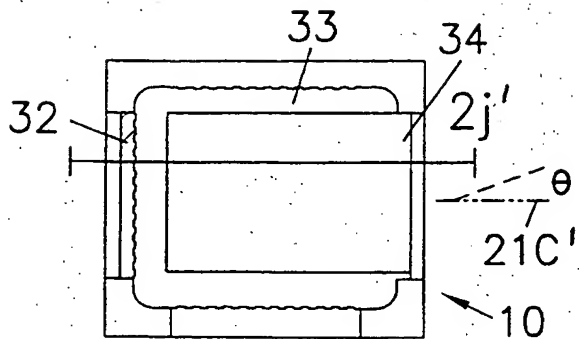


Fig. 2i

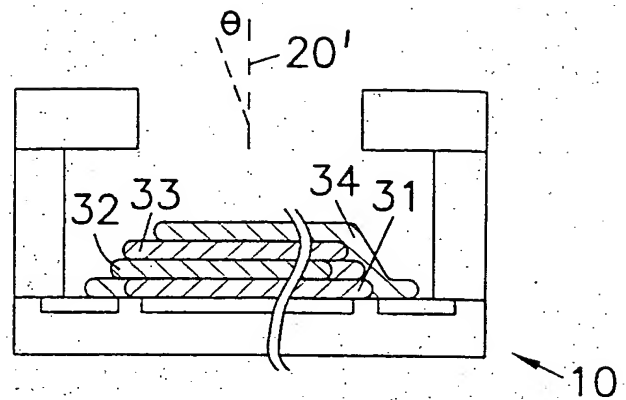


Fig. 2j

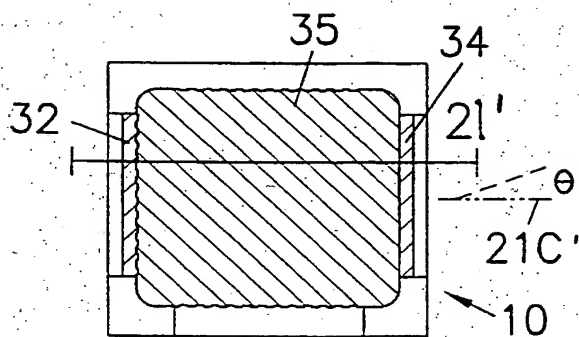


Fig. 2k

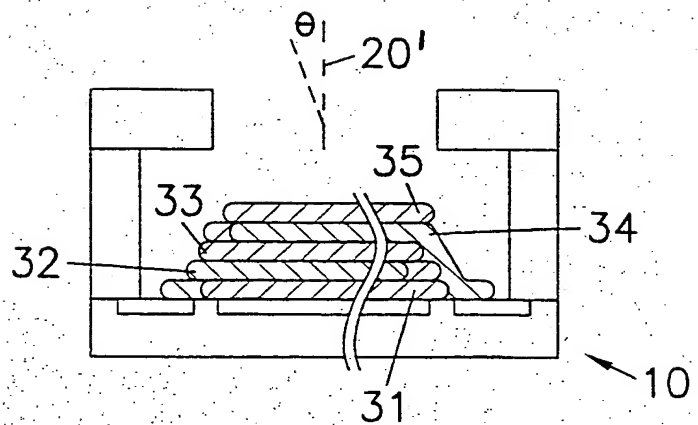


Fig. 2l

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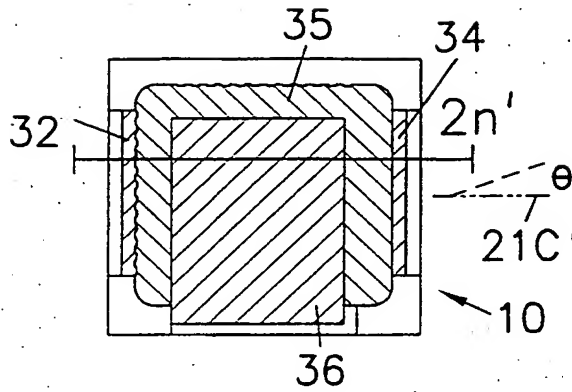


Fig. 2m

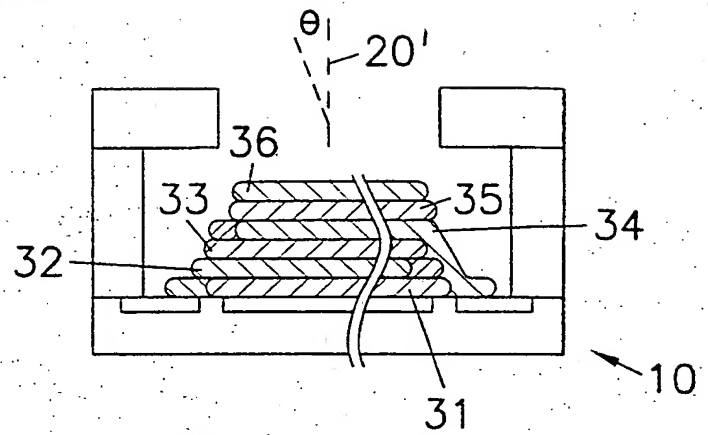


Fig. 2n

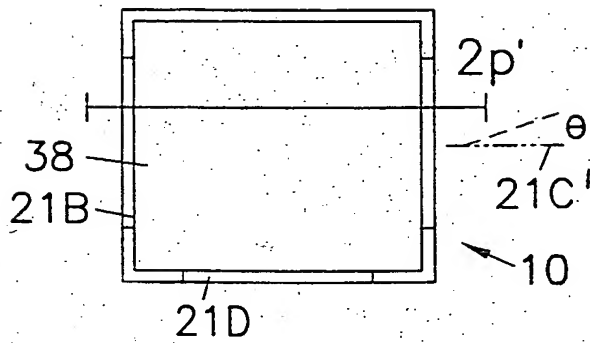


Fig. 2o

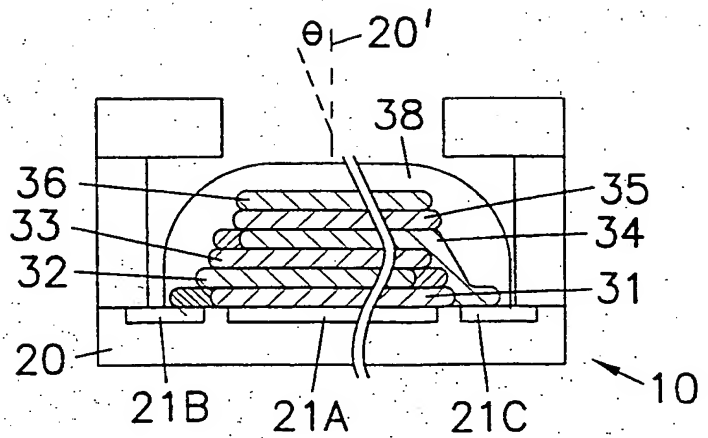


Fig. 2p

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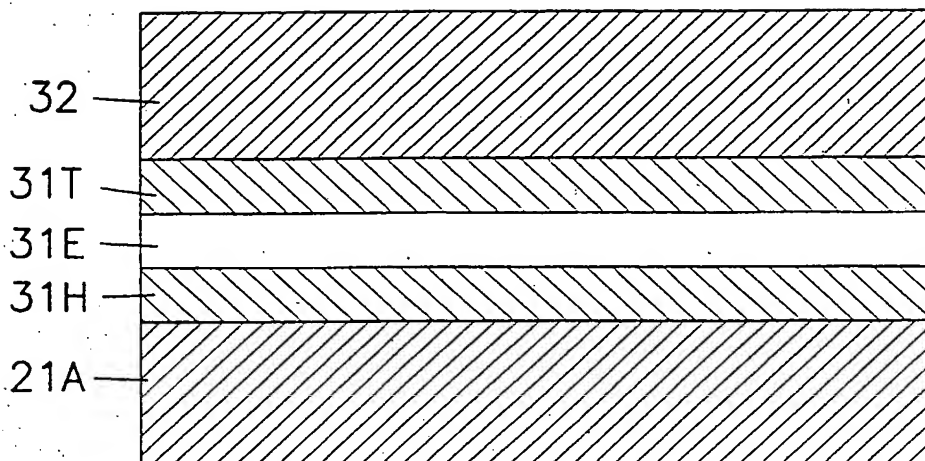


Fig. 3

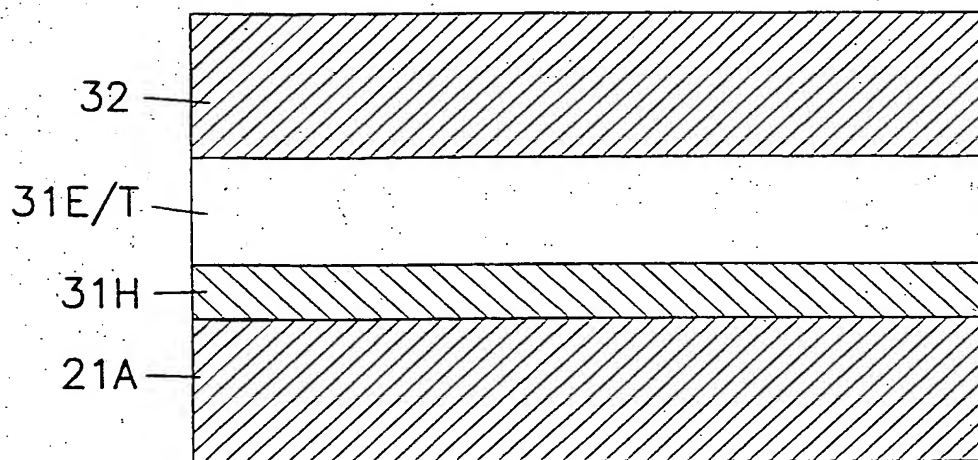


Fig. 4

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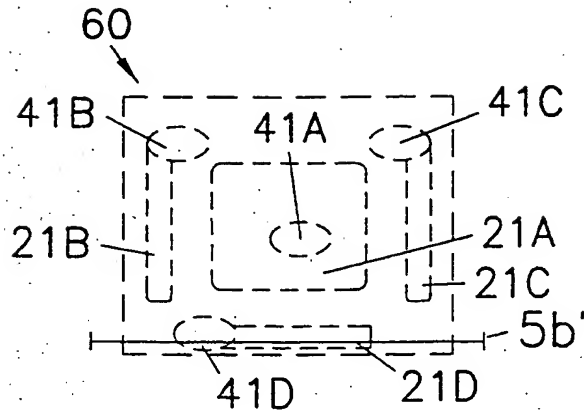


Fig. 5a

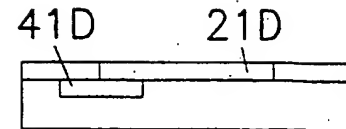


Fig. 5b

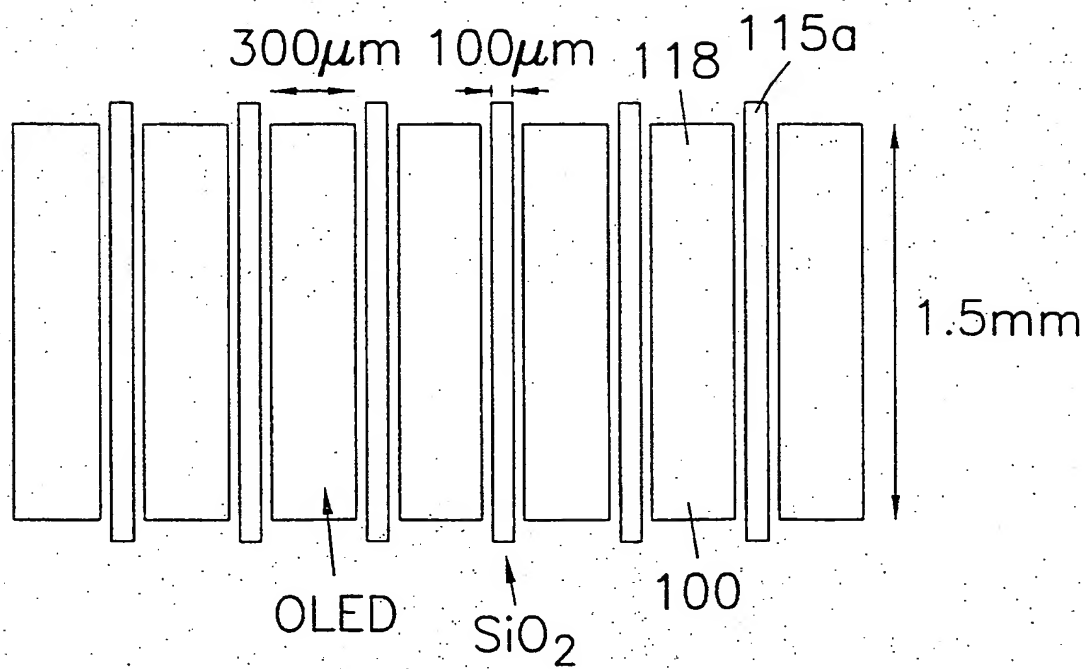


Fig. 17a



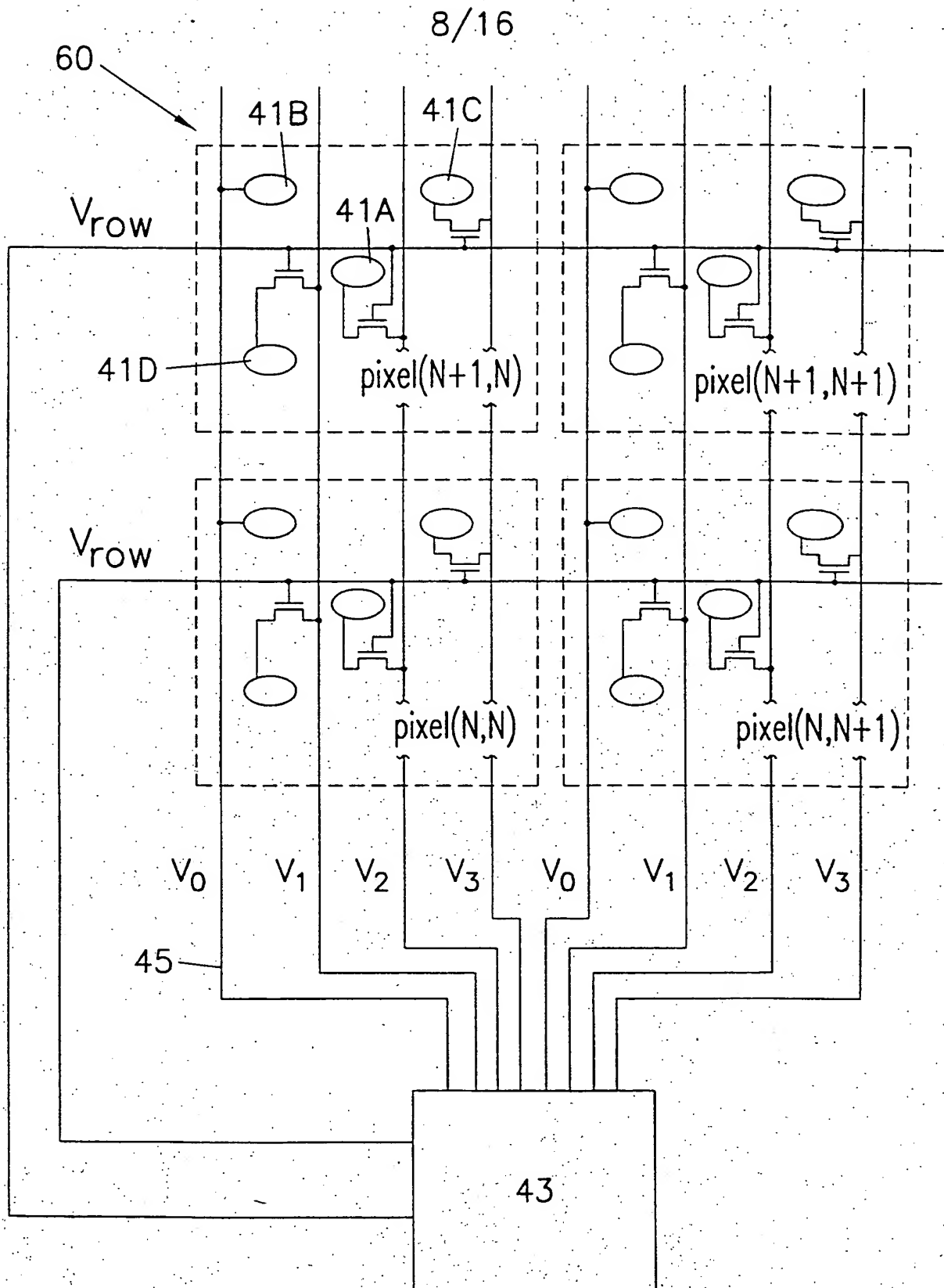


Fig. 6

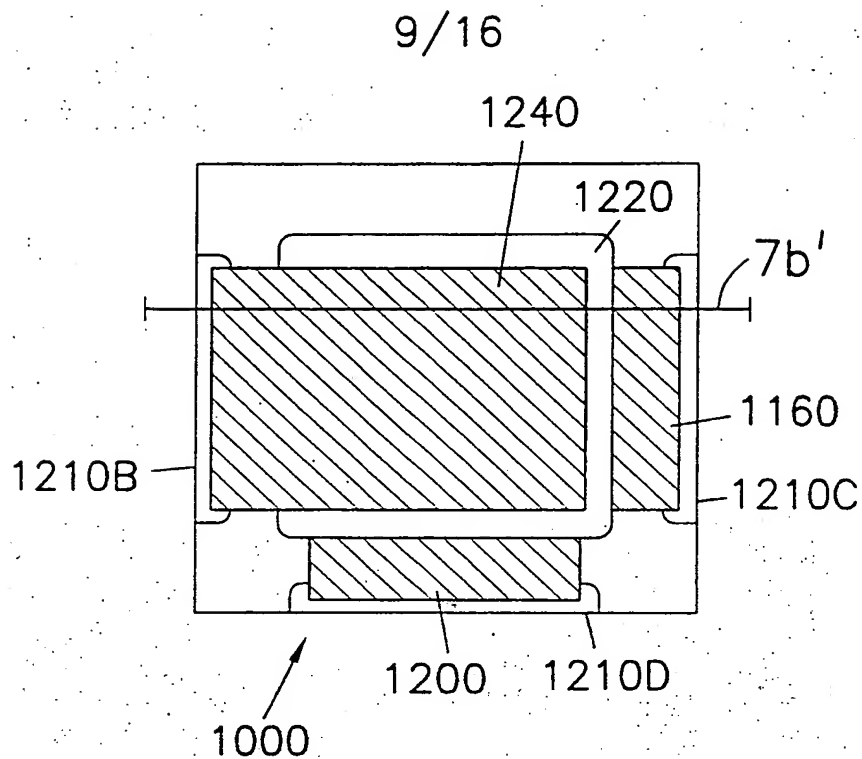


Fig. 7a

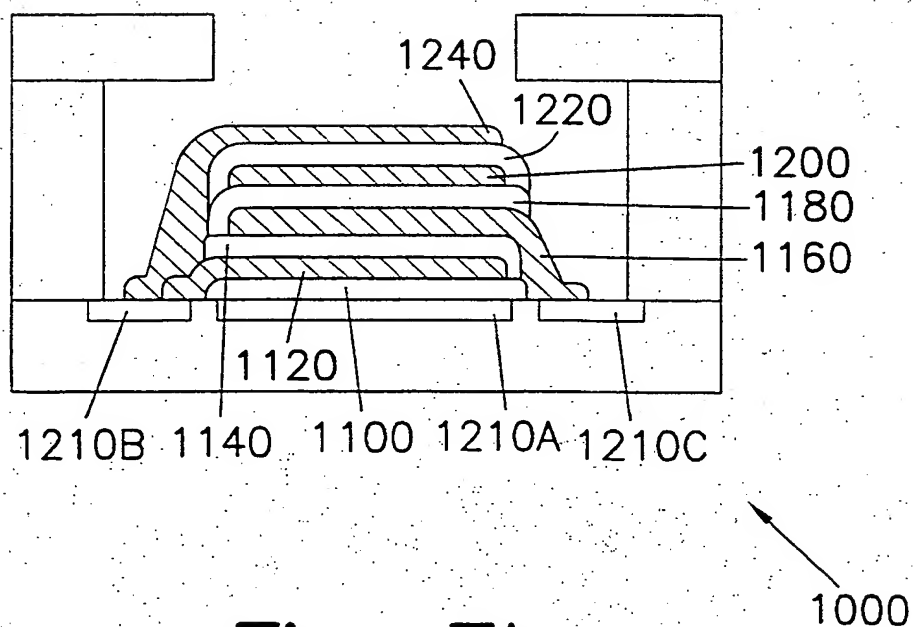


Fig. 7b

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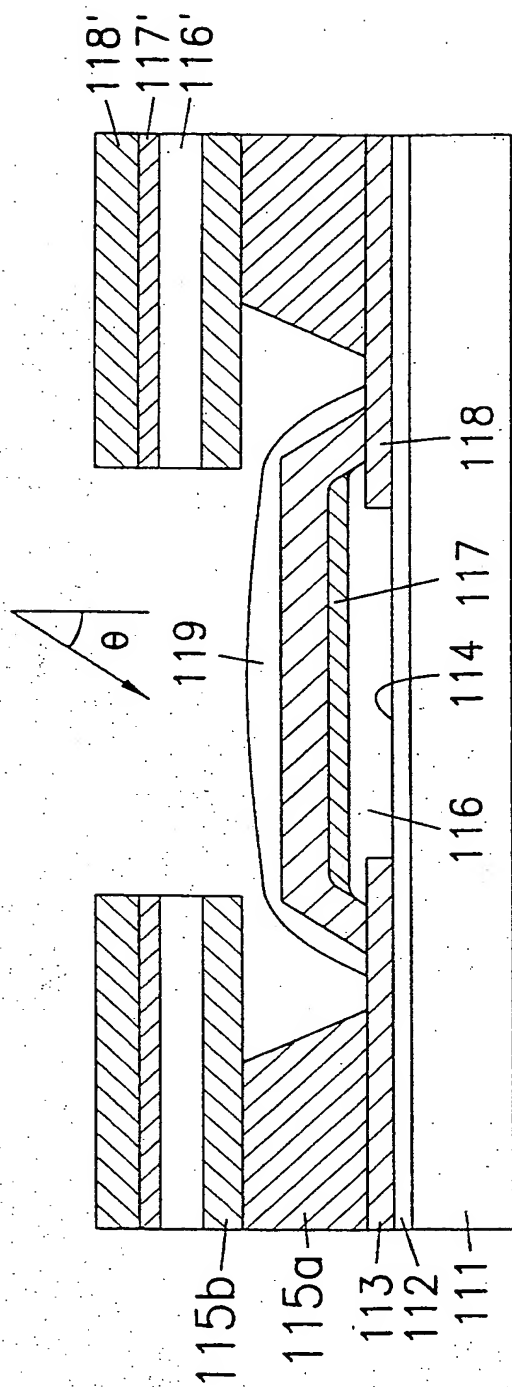


Fig. 8

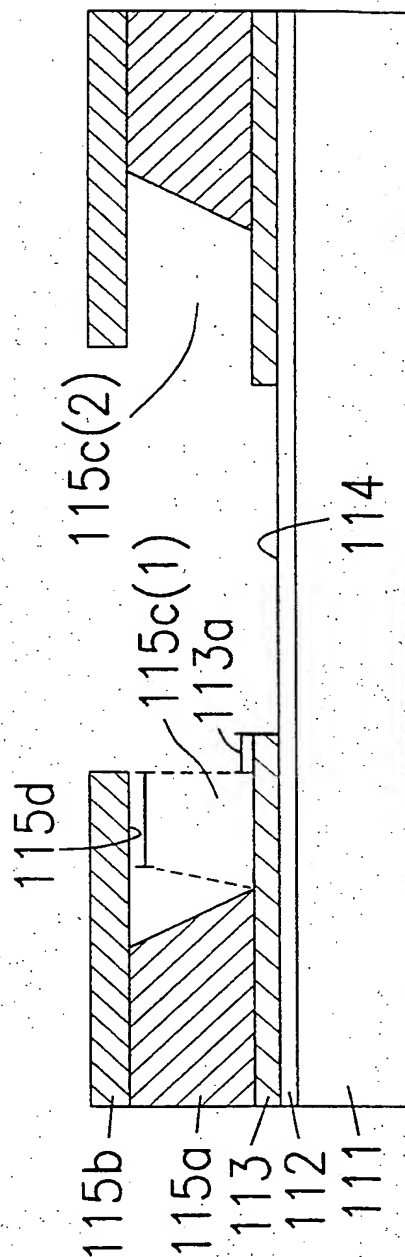


Fig. 10

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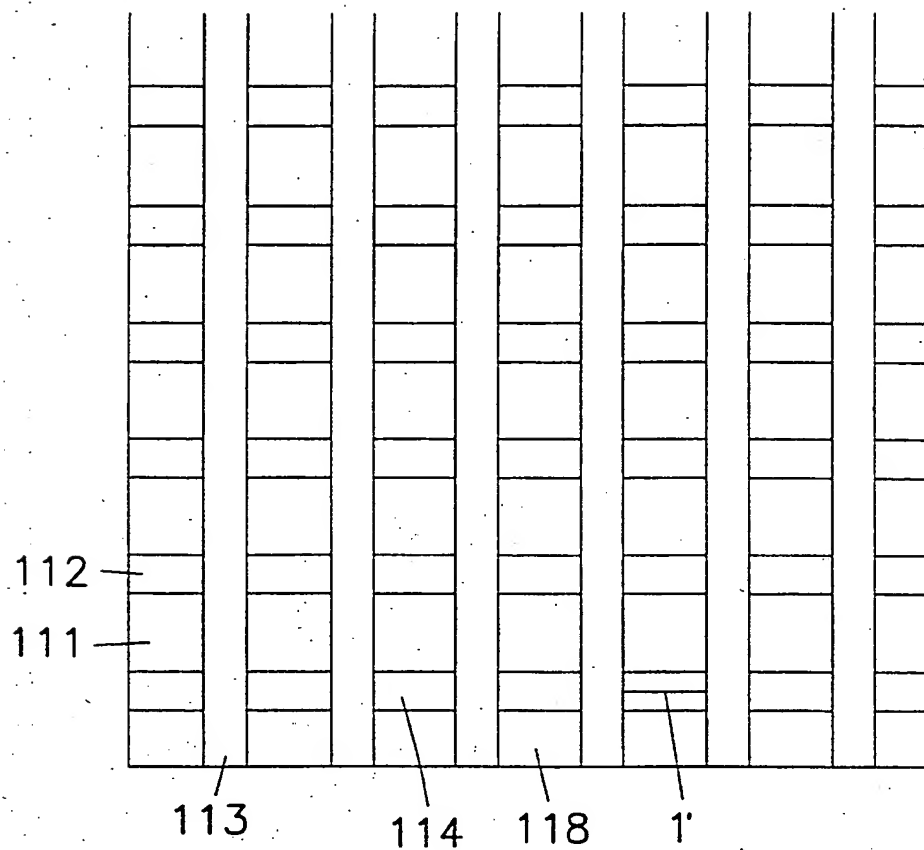


Fig. 9

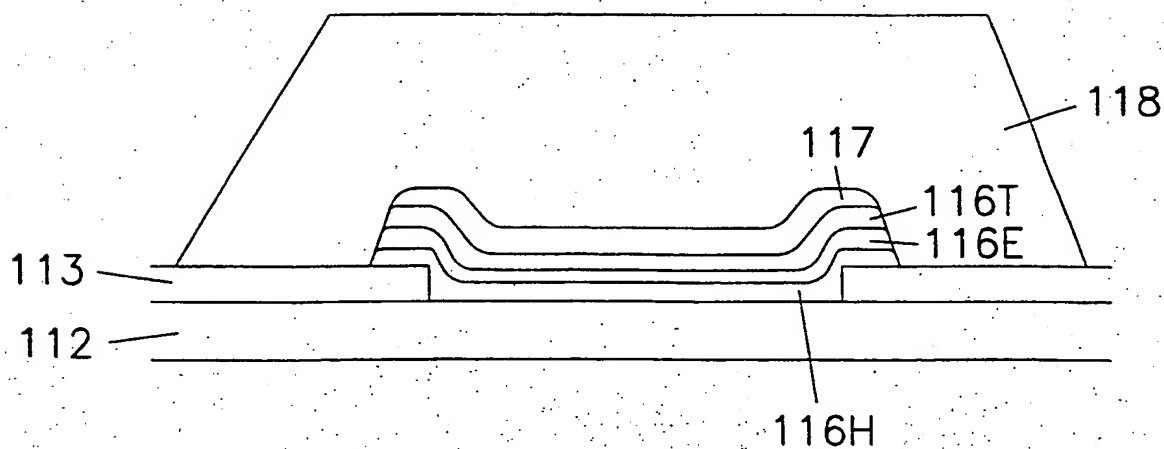


Fig. 12

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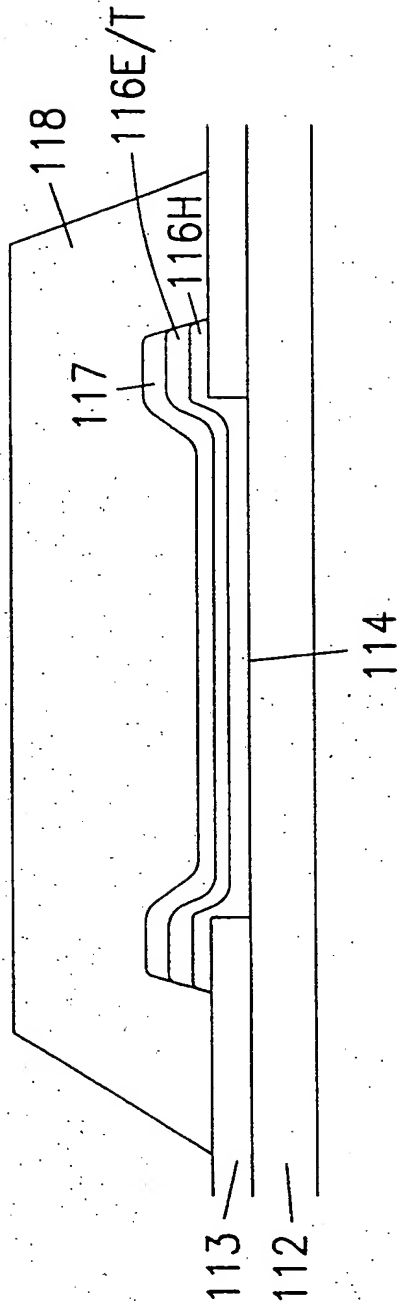


Fig. 13

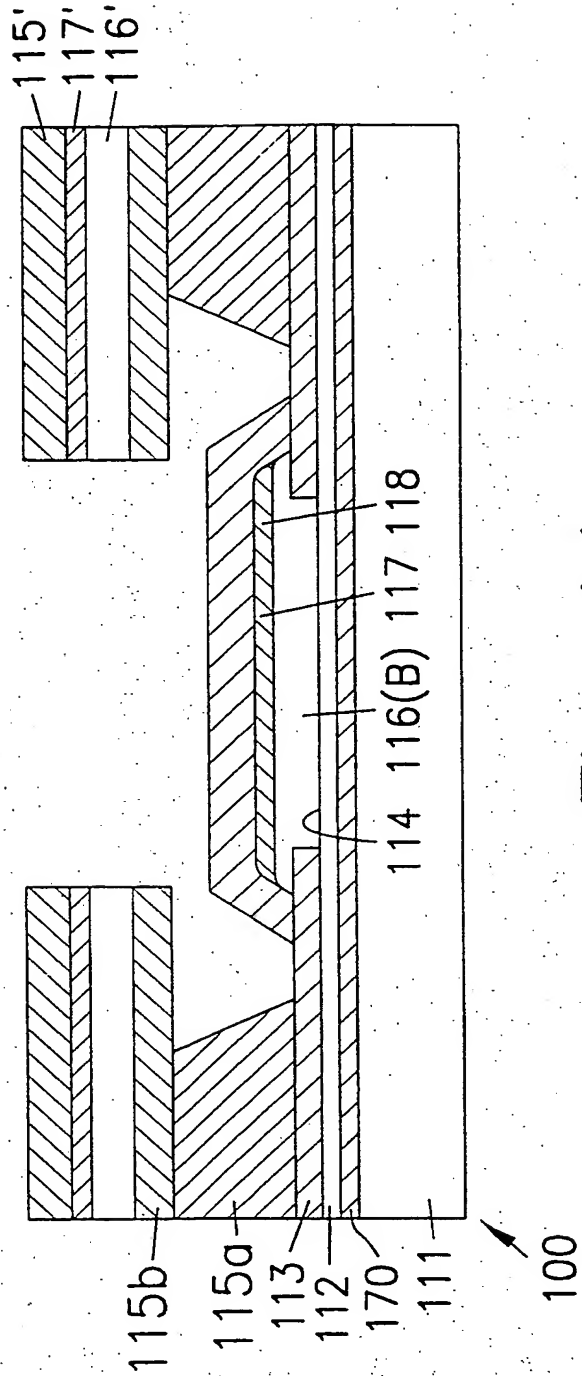


Fig. 14

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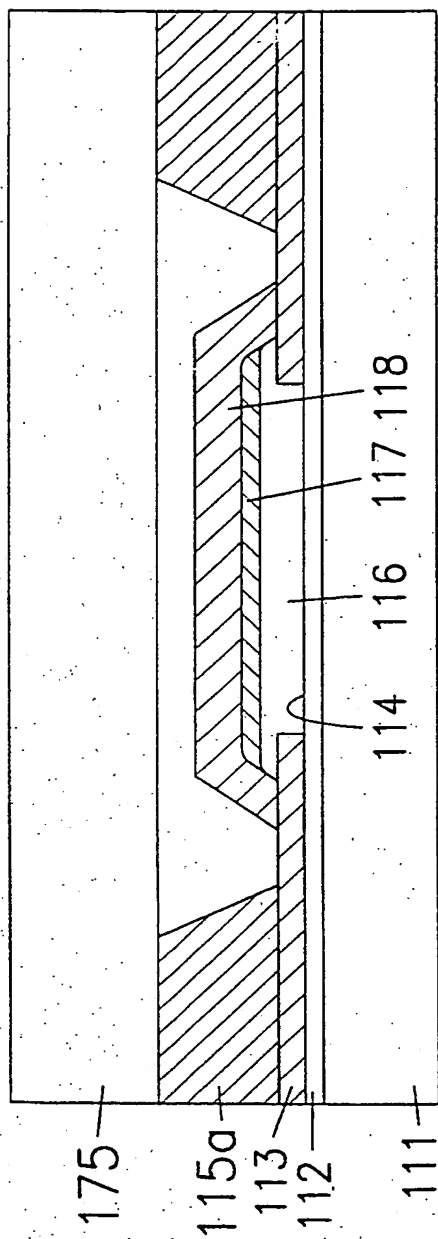


Fig. 15

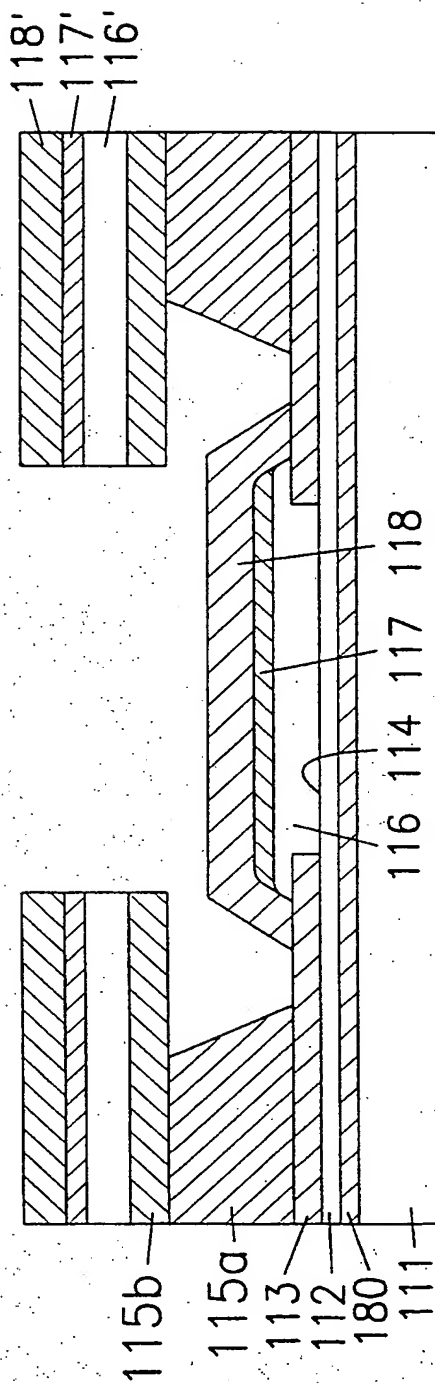


Fig. 16

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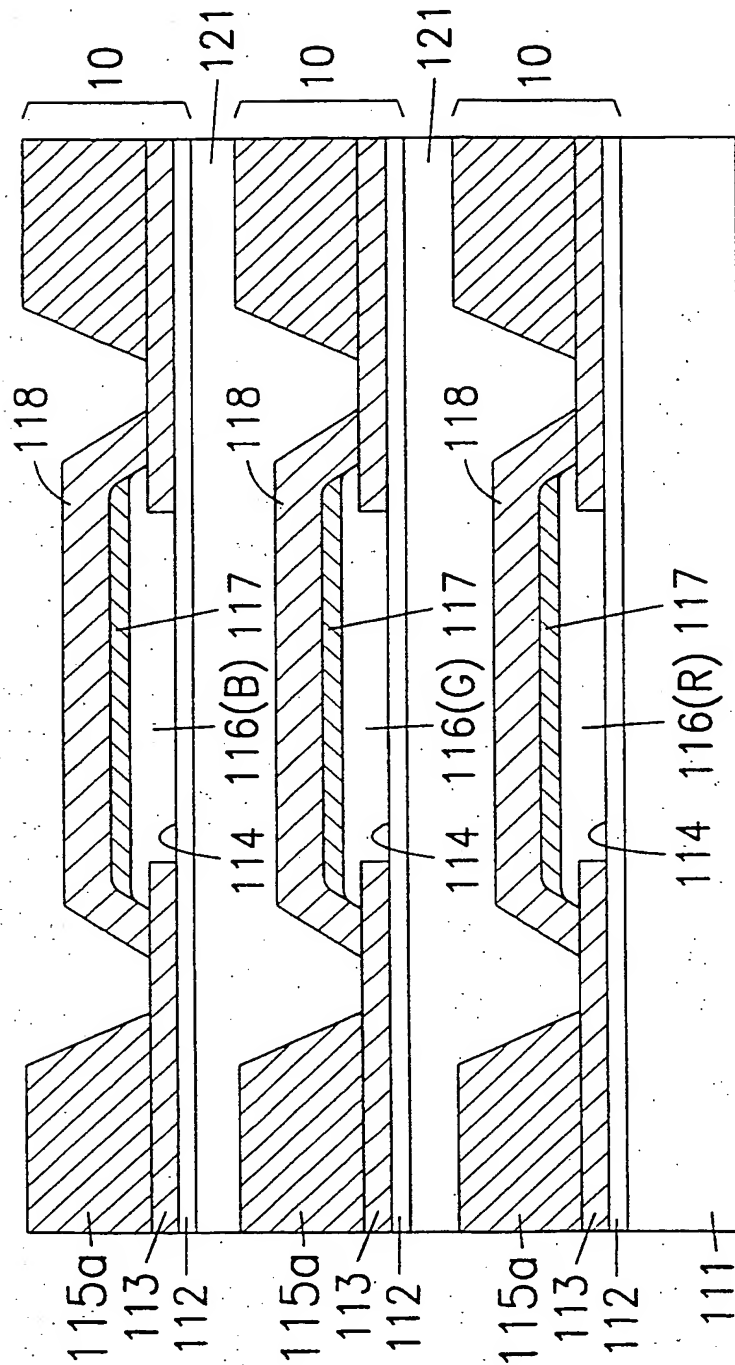


Fig. 11

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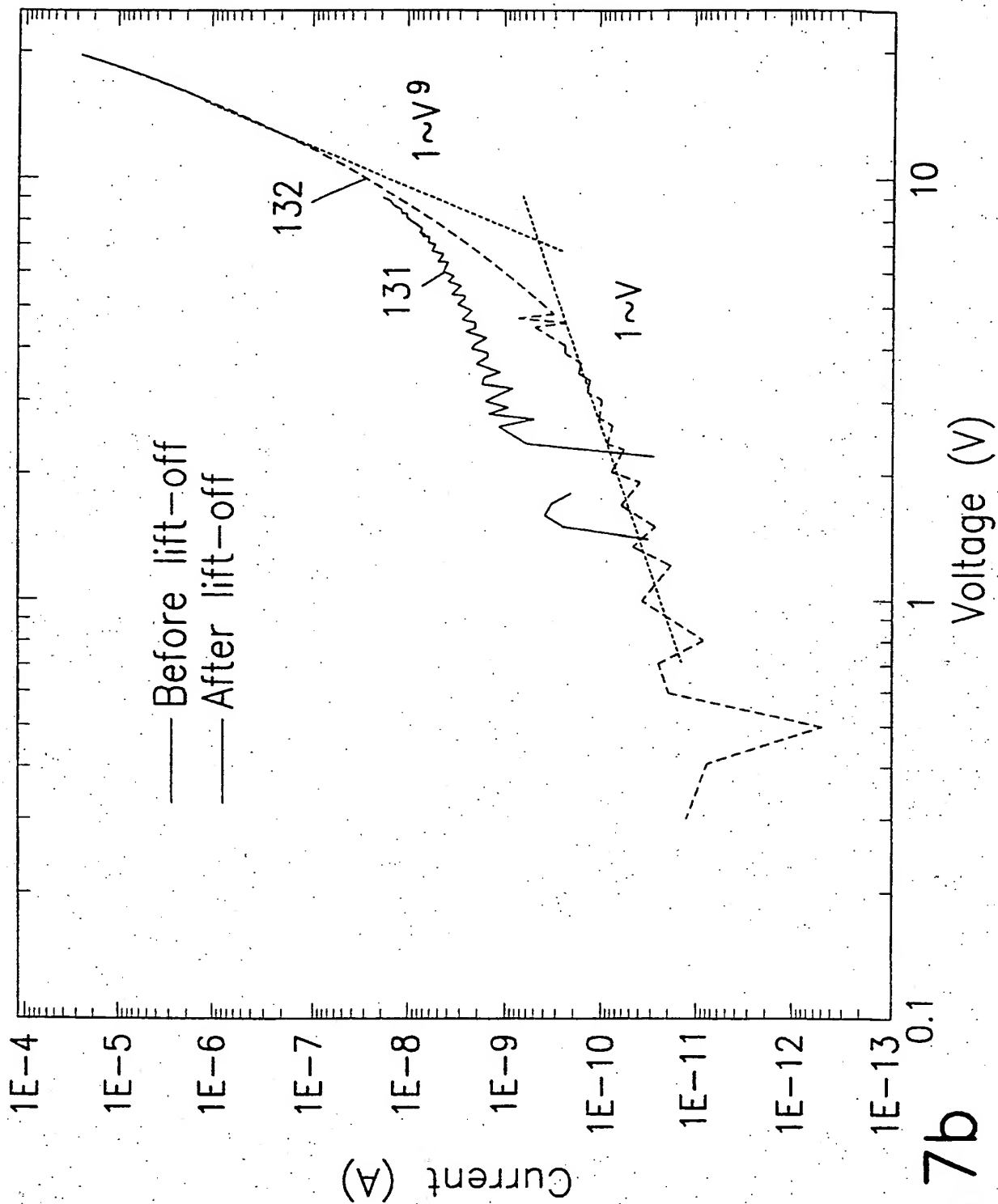


Fig. 17b



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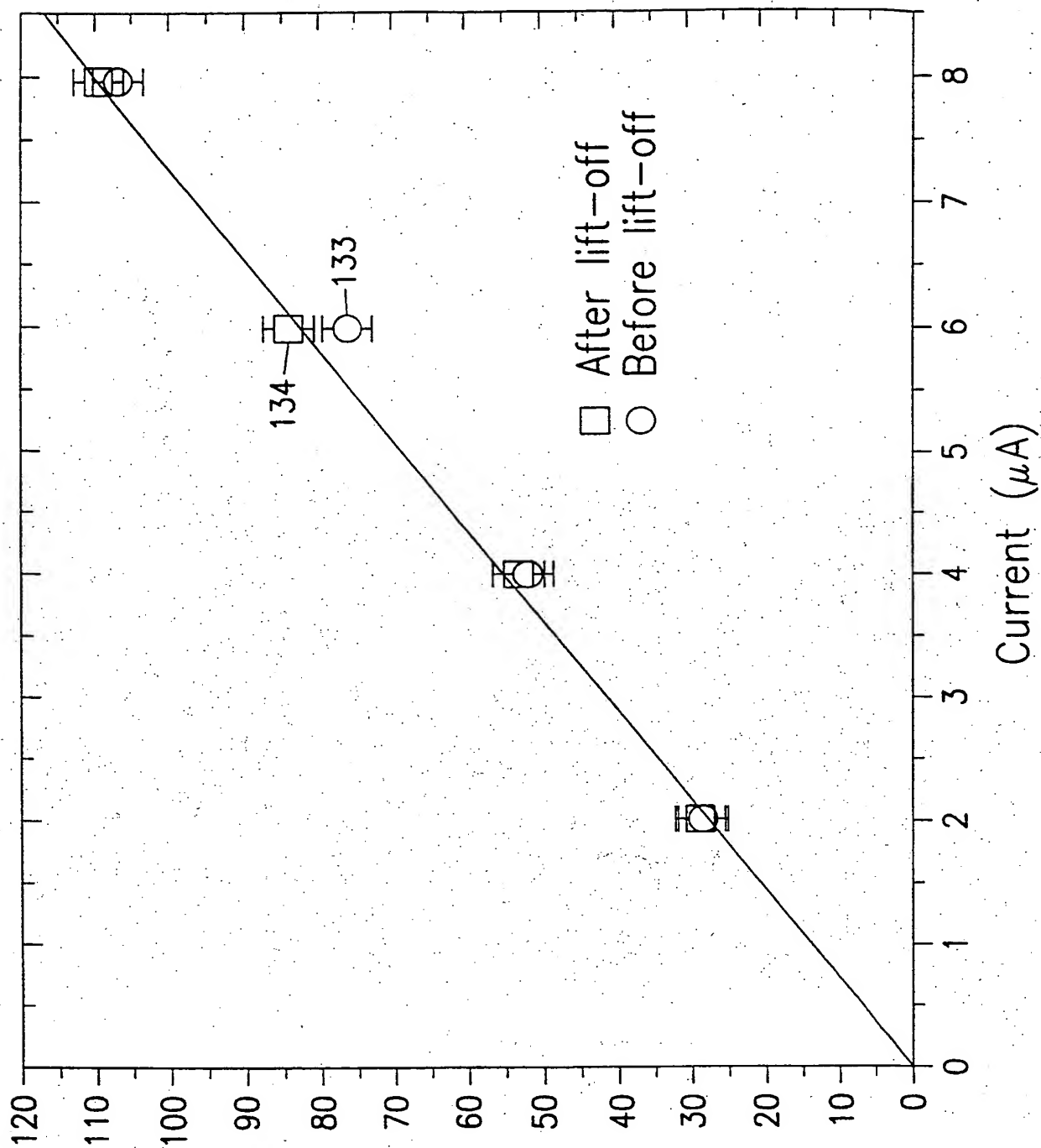


Fig. 17c

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US98/25256**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) :B05D 1/32

US CL : 438/35

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 438/22, 23, 28, 29, 34, 99; 257/12, 13, 40, 88, 89, 90, 96, 97, 100

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, INSPEC

SEARCH TERMS: OLED, PHOTORESIST OVERHANG, FLUORESCENT

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,641,611 A (SHIEH ET AL) 24 June 1997 (24/06/97), see Abstract, Fig. 7	1-21

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

27 JANUARY 1999

Date of mailing of the international search report

08 MAR 1999

Name and mailing address of the ISA/US  
Commissioner of Patents and Trademarks  
Box PCT  
Washington, D.C. 20231

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Authorized officer

KEITH CHRISTIANSON

Telephone No. (703) 305-4029

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US98/25256**Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)**

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 22,23  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:  
  
These claims recite an apparatus or device according to the method of claim 1, which is so unduly broad as to what constitutes the apparatus of device a thereby precluding any meaningful search on the subject matter of these claims.
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

- ☐ The additional search fees were accompanied by the applicant's protest.  
☐ No protest accompanied the payment of additional search fees.